

APPENDIX D
HYDROLOGY/HYDRAULIC STUDY

San Elijo Lagoon Restoration Project Hydrology/Hydraulic Study

Final Report

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This hydrology and hydraulic study report has been prepared by or under supervision of the following Registered Engineer. The Registered Civil Engineer attests to the technical information contained herein and has judged the qualifications of any technical specialists providing engineering data upon which recommendations, conclusions, and decisions are based.



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TABLE OF CONTENTS

1.0 INTRODUCTION.....	1
2.0 SCOPE OF WORK	4
3.0 ALTERNATIVE WETLANDS RESTORATION CONCEPTS	5
3.1 No Project - Existing Conditions	5
3.2 Alternative 1A – Minimum Changes.....	5
3.3 Alternative 1B – Maximum Habitat Diversity, Existing Inlet location	8
3.4 Alternative 2A – Maximum Habitat Diversity, New Inlet location	8
3.5 Alternative 2B – Maximum Tidal Expression.....	8
3.6 Summary of Inlet and Channel Dimensions	8
3.6.1 Hwy 101 Bridge	12
3.6.2 Railroad Bridge	13
3.6.3 Interstate 5 Freeway Bridge.....	14
4.0 TIDAL AND FLOOD HYDRAULICS STUDY	16
4.1 Model Selection and Description	16
4.2 Model Setup	18
4.2.1 Model Area	18
4.2.2 Bathymetry	19
4.2.3 Finite Element Mesh	21
4.2.4 Boundary Conditions	28
4.2.4.1 Tides.....	28
4.2.4.2 Modeling Tidal Series.....	29
4.2.4.3 Recorded Highest Tidal Series.....	30
4.2.4.4 Flood Flows from Creeks	31
4.3 Model Calibration for Existing Tidal Conditions.....	33
4.3.1 Model Setup for Calibration	35
4.3.2 Model Sensitivity.....	36
4.3.3 Calibration Results.....	36
4.3.4 Verification Results	38
4.4 Hydraulic Modeling Results	41
4.4.1 Flood Flow Hydraulics.....	44
4.4.1.1 Maximum Water Levels.....	44
4.4.2 Tidal Hydraulics and Hydrology for 2015	45
4.4.2.1 Tidal Elevations.....	46
4.4.2.2 Tidal Inundation Frequency.....	50
4.4.2.3 Tidal Hydraulics at the Tidal Inlet	53
4.4.3 Tidal Hydraulics in the Year 2065 with Sea Level Rise	55
4.4.3.1 Tidal Elevations.....	55
4.4.3.2 Tidal Inundation Frequency.....	60
4.4.3.3 Tidal Hydraulics at the Tidal Inlet	64
5.0 SUMMARY AND CONCLUSIONS.....	66
6.0 REFERENCES.....	70

LIST OF FIGURES

Figure 1-1: Project Vicinity Map	2
Figure 1-2: Project Study Area	3
Figure 3-1: No Project - Existing Habitat	6
Figure 3-2: Alternative 1A	7
Figure 3-3: Alternative 1B	9
Figure 3-4: Alternative 2A	10
Figure 3-5: Alternative 2B	11
Figure 3-6: HW 101 Bridge (Existing Lagoon Inlet)	13
Figure 3-7: Railroad Bridge	14
Figure 3-8: Interstate-5 Bridge	15
Figure 4-1: Numerical Modeling Area	19
Figure 4-2: Existing Bathymetry for the Entire Modeling Area	20
Figure 4-3: Existing Lagoon Bathymetry	21
Figure 4-4: RMA2 Model Mesh for Existing Conditions	23
Figure 4-5: RMA2 Modeling Mesh for Alternative 1A	24
Figure 4-6: RMA2 Modeling Mesh for Alternative 1B	25
Figure 4-7: RMA2 Modeling Mesh for Alternative 2A	26
Figure 4-8: RMA2 Modeling Mesh for Alternative 2B	27
Figure 4-9: Modeling Tidal Series	30
Figure 4-10: Recorded Highest Tidal Series	31
Figure 4-11: Flood Hydrographs	32
Figure 4-12: RMA2 Model Calibration Gage Locations	34
Figure 4-13: RMA2 Model Calibration Results at the Railroad Bridge	37
Figure 4-14: RMA2 Model Calibration Results at I-5 Bridge	38
Figure 4-15: RMA2 Model Verification Gage Locations (Created in Google Earth)	39
Figure 4-16: RMA2 Model Verification Results at the Tidal Inlet	39
Figure 4-17: RMA2 Model Verification Results at Segment 2	40
Figure 4-18: RMA2 Model Verification Results at Segment 1	40
Figure 4-19: Virtual Gage Locations for Existing Conditions and Alternatives 1A and 1B	42
Figure 4-20: Virtual Gage Locations for Alternatives 2A and 2B	43
Figure 4-21: Predicted Tidal Elevations for No Project at 2015	47
Figure 4-22: Predicted Tidal Elevations for Alternative 1A at 2015	48
Figure 4-23: Predicted Tidal Elevations for Alternative 1B at 2015	48
Figure 4-24: Predicted Tidal Elevations for Alternative 2A at 2015	49
Figure 4-25: Predicted Tidal Elevations for Alternative 2B at 2015	49
Figure 4-26: Inundation Frequency of No Project at 2015	51
Figure 4-27: Inundation Frequency for Alternative 1A at 2015	51
Figure 4-28: Inundation Frequency for Alternative 1B at 2015	52
Figure 4-29: Inundation Frequency for Alternative 2A at 2015	52
Figure 4-30: Inundation Frequency for Alternative 2B at 2015	53
Figure 4-31: Alternative 1A Tidal Inlet Velocity and Tidal Elevations at 2015	55
Figure 4-32: Predicted Tidal Elevations for No Project at 2065 Without Shoaling	57
Figure 4-33: Predicted Tidal Elevations for Alternative 1A at 2065 Without Shoaling	58
Figure 4-34: Predicted Tidal Elevations for Alternative 1B at 2065 Without Shoaling	58
Figure 4-35: Predicted Tidal Elevations for Alternative 2A at 2065 Without Shoaling	59
Figure 4-36: Predicted Tidal Elevations for Alternative 2B at 2065 Without Shoaling	59
Figure 4-37: Inundation Frequency for No Project at 2065	61
Figure 4-38: Inundation Frequency for Alternative 1A at 2065	62

Figure 4-39: Inundation Frequency for Alternative 1B at 2065.....	62
Figure 4-40: Inundation Frequency for Alternative 2A at 2065.....	63
Figure 4-41: Inundation Frequency for Alternative 2B at 2065.....	63

LIST OF TABLES

Table 3-1: Summary of Inlet and Channel Dimensions.....	12
Table 4-1: Model Mesh Elements and Nodes.....	28
Table 4-2: Recorded Water Levels at La Jolla (1983-2001 Tidal Epoch).....	28
Table 4-3: Suite of RMA2 Numerical Hydrodynamic Simulations	33
Table 4-4: Setup Values For Model Calibration	35
Table 4-5: Maximum 100-Year Flood Elevation (ft, NGVD) in the Wetlands in 2015 Based on +5.4-ft NGVD (Recorded Highest) Downstream Tidal Elevation	45
Table 4-6: Predicted Tidal Ranges for 2015	46
Table 4-7: Predicted Spring High and Low Tidal Elevations for 2015	46
Table 4-8: Summary of Tidal Inlet Hydraulic Results at 2015	54
Table 4-9: Summary of Modeling Tidal Range at 2015 and 2065 Without Shoaling	57
Table 4-10: Summary of Spring High and Low Tides at 2065 Without Shoaling	57
Table 4-11: Summary of Tidal Inlet Hydraulic Results at 2065	64

1.0 INTRODUCTION

The San Elijo Lagoon is located approximately 20 miles north of the City of San Diego, between the Cities of Solana Beach and Encinitas, as shown in Figure 1-1. The California Department of Fish and Game generally owns the San Elijo Lagoon west of Interstate 5 (I-5), the County of San Diego generally owns the Lagoon east of I-5, and the San Elijo Lagoon Conservancy (SELC) owns smaller areas west of I-5. The study area boundary is illustrated in Figure 1-2.

The Lagoon is a coastal wetland with significant biological and ecological resources. The San Elijo Lagoon Restoration Project (SELRP) is an effort to restore the Lagoon functions and values given the constraints placed on it by surrounding current and historic development activities. The project aims to enhance the tidal prism of the Lagoon by proposing modifications to known infrastructure “choke points” such as Highway 101, the North County Transit District (NCTD) railroad, and the I-5 freeway. The approximate target construction start date of the SELRP is the year 2015.

The overarching goal of the SELRP is to protect, restore, then maintain, via adaptive management, the San Elijo Lagoon ecosystem and the adjacent uplands to perpetuate native flora and fauna characteristics of Southern California, as well as to restore, then maintain estuarine and brackish marsh hydrology (EDAW 2009). A clear challenge of this project is a design that will protect and promote biodiversity by protecting habitat types over a very long period of time.

This project goal can be further refined into three categories of objectives:

- Physical restoration of lagoon estuarine hydrologic functions;
- Biological restoration of habitat and species within the lagoon; and
- Management and maintenance to ensure long-term viability of the restoration efforts.

The SELRP is located primarily within tidal lands, and will be designed to provide optimal wetland habitat based on tidal hydrology. This study analyzes tidal hydraulics and hydrology, and storm flood hydraulics to determine the conditions predicted to exist at the marsh in the future. This study serves as the technical foundation for multiple subsequent studies. Tidal hydrology and hydraulics provides the basis for determining future habitat distribution, tidal inlet stability, shoaling and scour in the lagoon, tidal muting, and water quality. Storm flow hydrology serves as the basis for design of structures, and for analyzing water quality and future flood conditions. These additional studies will occur in the future and directly utilize the data and results generated for this study.



Figure 1-1: Project Vicinity Map

(Source: EDAW, 2009)

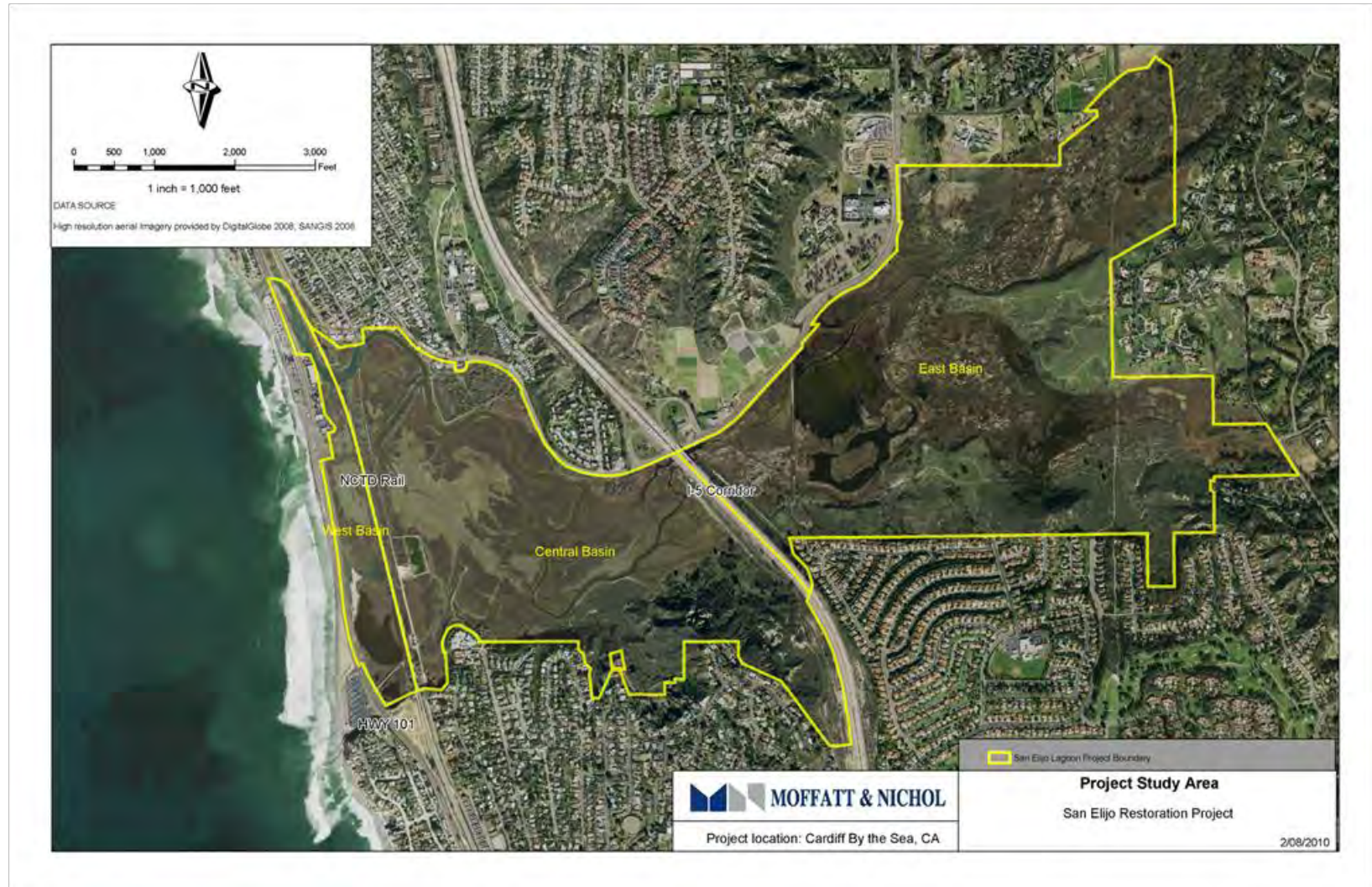


Figure 1-2: Project Study Area

2.0 SCOPE OF WORK

The scope of work for this study consists of analyzing tidal and storm flood hydraulics for all project alternatives using the RMA-2 model previously employed by the U.S. Army Corps of Engineers (USACE) for this site. Model results will provide water level and flow velocity data for use in assessing the performance of each alternative. These data will be used to:

- Analyze the potential for increased flooding of adjacent areas from restoration;
- Predict the hydrology required to establish new wetland habitat areas;
- Size the openings of a new tidal inlet and channels under highway and railroad bridges;
- Estimate the long-term stability of the tidal inlet (in a separate study), and
- Provide the basis for water quality modeling (in a separate study).

Specific modeling tasks include:

1. Modify the modeling domain (mesh grid) to include all areas of interest and potential influence. The mesh will need to be modified to stabilize the model, to optimally represent existing bathymetry, and to cover all areas to be modified for proposed conditions.
2. Calibrate the model to existing hydraulic conditions, with limited verification and sensitivity analyses. The hydrodynamic model is to be calibrated to match tide, current and discharge conditions measured in the field by the SELC and/or USACE during a specific time period. Model predictions are to be verified by replicating conditions also measured in the field by the SELC and/or USACE during a different time period from the calibration data set if the data are available. This task does not include any additional field data collection. Sensitivity analyses will be accomplished by adjusting dependent variables within the model (e.g., bed roughness, eddy viscosity and possibly others) to ascertain model sensitivity and range of predictions for hydraulics only.
3. Run the model to predict hydraulic and hydrologic conditions for five options, including existing conditions. The model will be used to predict future conditions for five alternatives.

3.0 ALTERNATIVE WETLANDS RESTORATION CONCEPTS

Five project alternatives have been identified by the Stakeholder Committee as likely to be included in the environmental document. They include:

- No Project – Existing Conditions;
- Alternative 1A – Minimum Changes;
- Alternative 1B – Maximum Habitat Diversity, Existing Inlet Location;
- Alternative 2A – Maximum Habitat Diversity, New Inlet Location; and
- Alternative 2B – Maximum Tidal Expression.

The conceptual design of these alternatives is required to perform engineering analyses and numerical modeling of their performance. Brief descriptions of the alternatives are provided below, and habitat graphics of all alternatives are provided in this section. More detailed descriptions of the alternatives are provided in the Final Alternatives Assessment (Nordby et al. 2012) Report.

3.1 No Project - Existing Conditions

No Project assumes no changes are made to the project site and existing conditions remain into perpetuity. The Lagoon presently experiences mouth constriction and manual re-opening annually, and sometimes more frequently. Tidal flushing is restricted, and water quality conditions are impaired for nutrients and sediment. Habitat is distributed at elevations and locations that are related to relic closed mouth conditions, and are progressively transitioning to distributions more reflective of managed mouth conditions. For example, mudflat habitat is located too high for a full tidal lagoon because it formed when the mouth was closed and Lagoon water levels were higher from impoundment. Now that the mouth is managed to be open, the mudflat is converting to vegetated marsh because hydrologic conditions are favorable for salt marsh plant growth. Figure 3-1 shows existing conditions.

3.2 Alternative 1A – Minimum Changes

Alternative 1A provides minimal physical changes to the site, with the exception of enlarging the main feeder channel throughout the site and redirecting its course just west of I-5. The main tidal channel is also extended farther into the East Basin and existing constricted channel connections are cleared and enlarged. Existing habitat areas will essentially remain intact. The tidal prism of Alternative 1A will be slightly increased compared to existing conditions. A relatively small area of transitional habitat above tidal elevations will be placed in the northwest portion of the Central Basin. Figure 3-2 shows Alternative 1A.

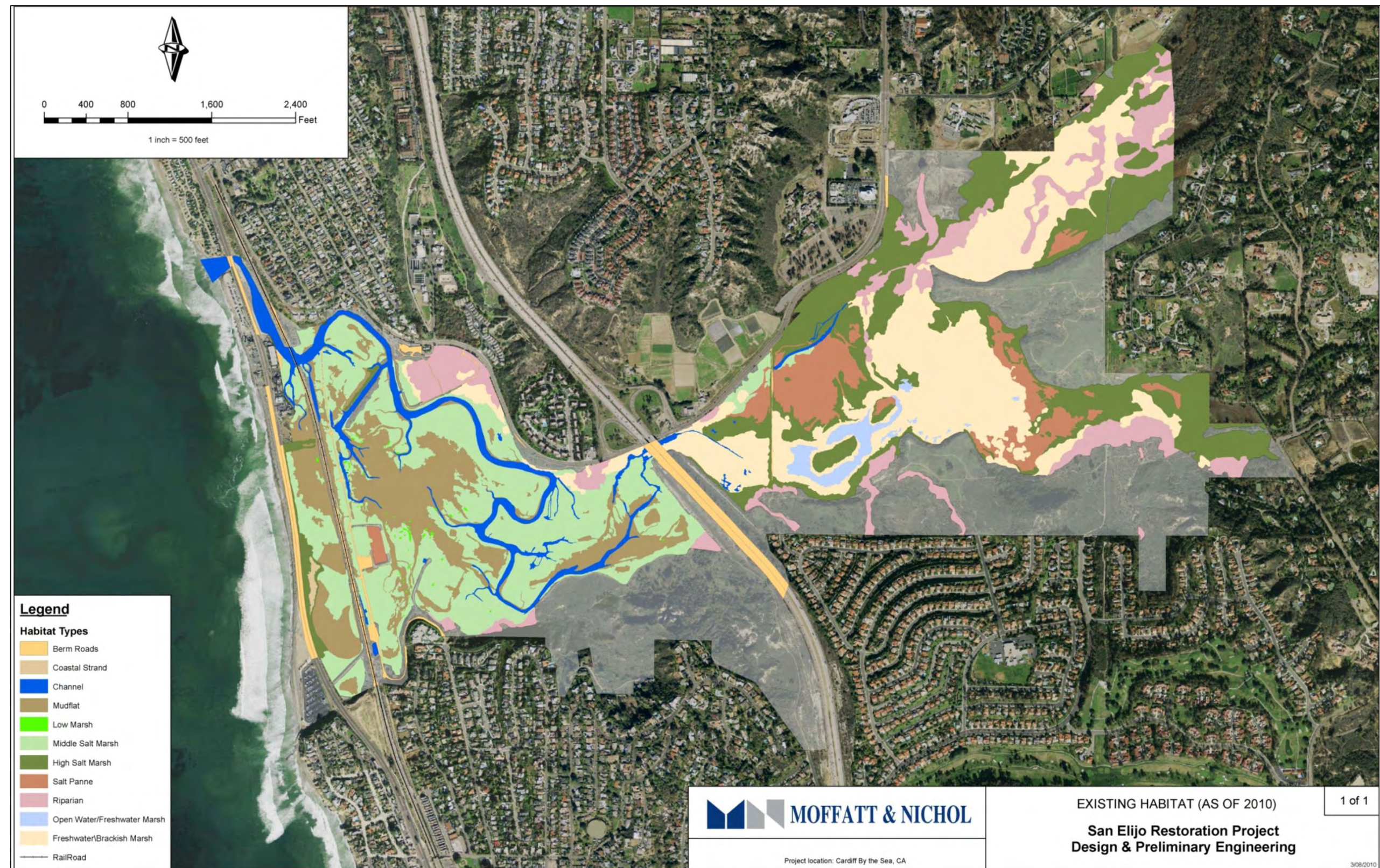


Figure 3-1: No Project - Existing Habitat

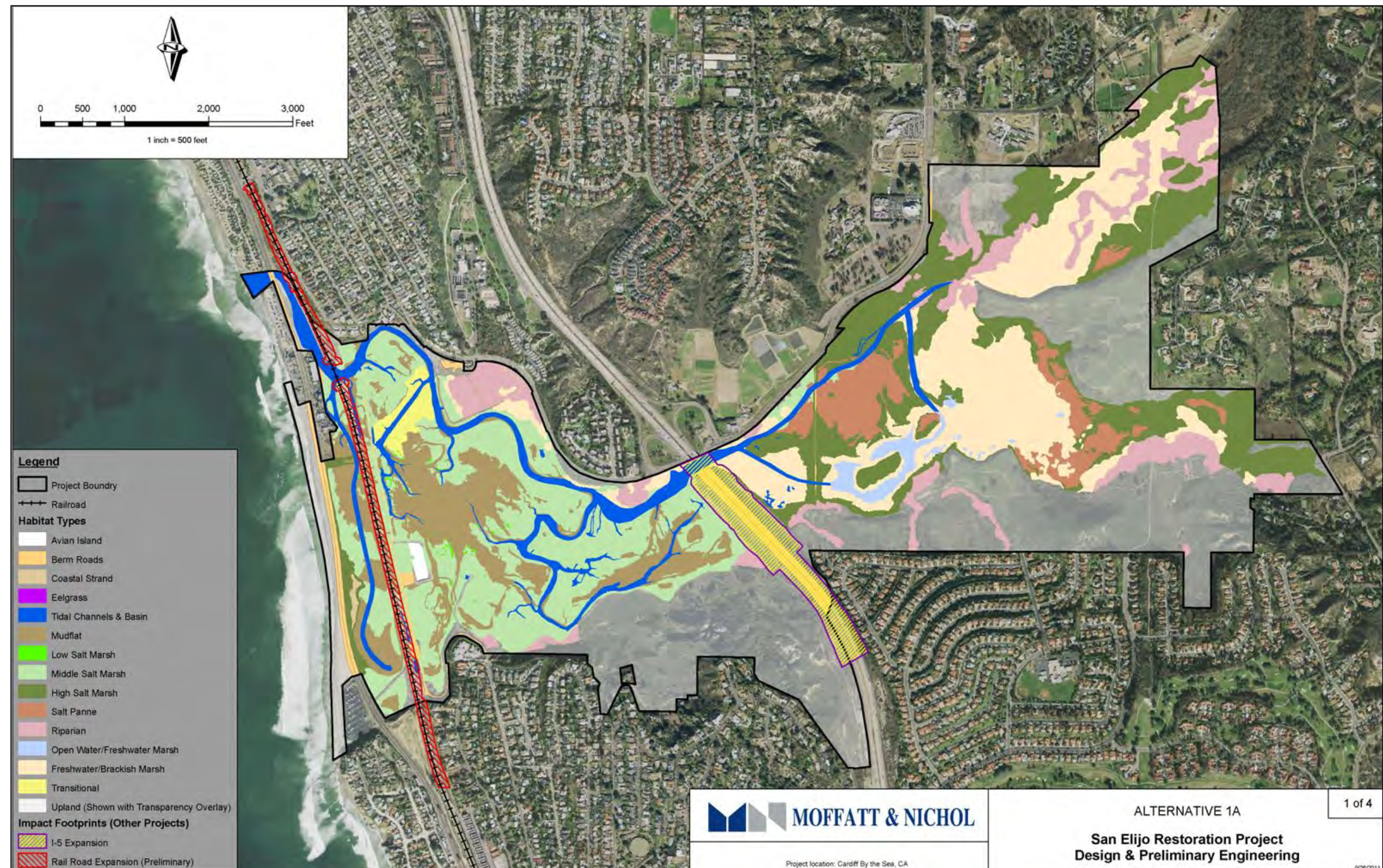


Figure 3-2: Alternative 1A

3.3 Alternative 1B – Maximum Habitat Diversity, Existing Inlet location

Alternative 1B provides a more substantial change to the existing site to create a greater diversity of habitats than currently exists. The existing tidal inlet remains the source of seawater, and the main tidal channel extends throughout the Lagoon. The main feeder channel is redirected just west of I-5, and extended farther into the East Basin. The channel in the East Basin is significantly enlarged in cross-sectional area to promote more tidal exchange east of I-5. The tidal prism of Alternative 1B will be significantly increased compared to Alternative 1A. Non-tidal habitat areas will still exist in the East Basin. Several areas of transitional habitat above tidal elevations will be placed in the western portion of the Central Basin. Figure 3-3 shows Alternative 1B.

3.4 Alternative 2A – Maximum Habitat Diversity, New Inlet location

Alternative 2A also provides changes to the existing site to create a greater diversity of habitats than presently exists. Seawater would enter the Lagoon via a new tidal inlet located south of the existing inlet and a new subtidal basin would be created just landward of the new inlet in the West and Central Basins. The main tidal channel would extend throughout the Lagoon and be redirected just west of I-5, and extend into the East Basin. The channel in the East Basin is identical to that for Alternative 1B. The tidal prism of Alternative 2A will increase compared to Alternative 1B. Non-tidal habitat areas remain in the East Basin. Transitional habitat areas above tidal elevations will also be included in the Central Basin as with Alternative 1B. Figure 3-4 shows Alternative 2A.

3.5 Alternative 2B – Maximum Tidal Expression

Alternative 2B provides the maximum level of change throughout the Lagoon. As the largest-tidal prism alternative, it requires a new tidal inlet to be located south of the existing inlet. Extensive subtidal basins will exist in the West, Central, and East Basins of the Lagoon. The East Basin becomes nearly entirely tidally-influenced habitat area. Figure 3-5 shows Alternative 2B.

3.6 Summary of Inlet and Channel Dimensions

The dimensions of each channel cross-section at each bridge constraint are optimized in the San Elijo Lagoon Bridge Optimization Study (Moffatt & Nichol 2012) and are shown in Table 3-1 below. The selection of optimum channel widths and depths was based on a sensitivity analysis conducted for each bridge crossing under typical dry weather tidal fluctuations and extreme stormflow conditions (100-year storm and 100-year water levels). Tidal range was used as the primary indicator for benefits to the wetland ecosystem, and extreme flood elevations were used to evaluate the potential for flooding of Manchester Avenue. Using these indicators, the optimum channel width and depth were identified as the point at which tidal range and flood conveyance are most favorable and further increases in channel width and depth result in only minimal benefit.

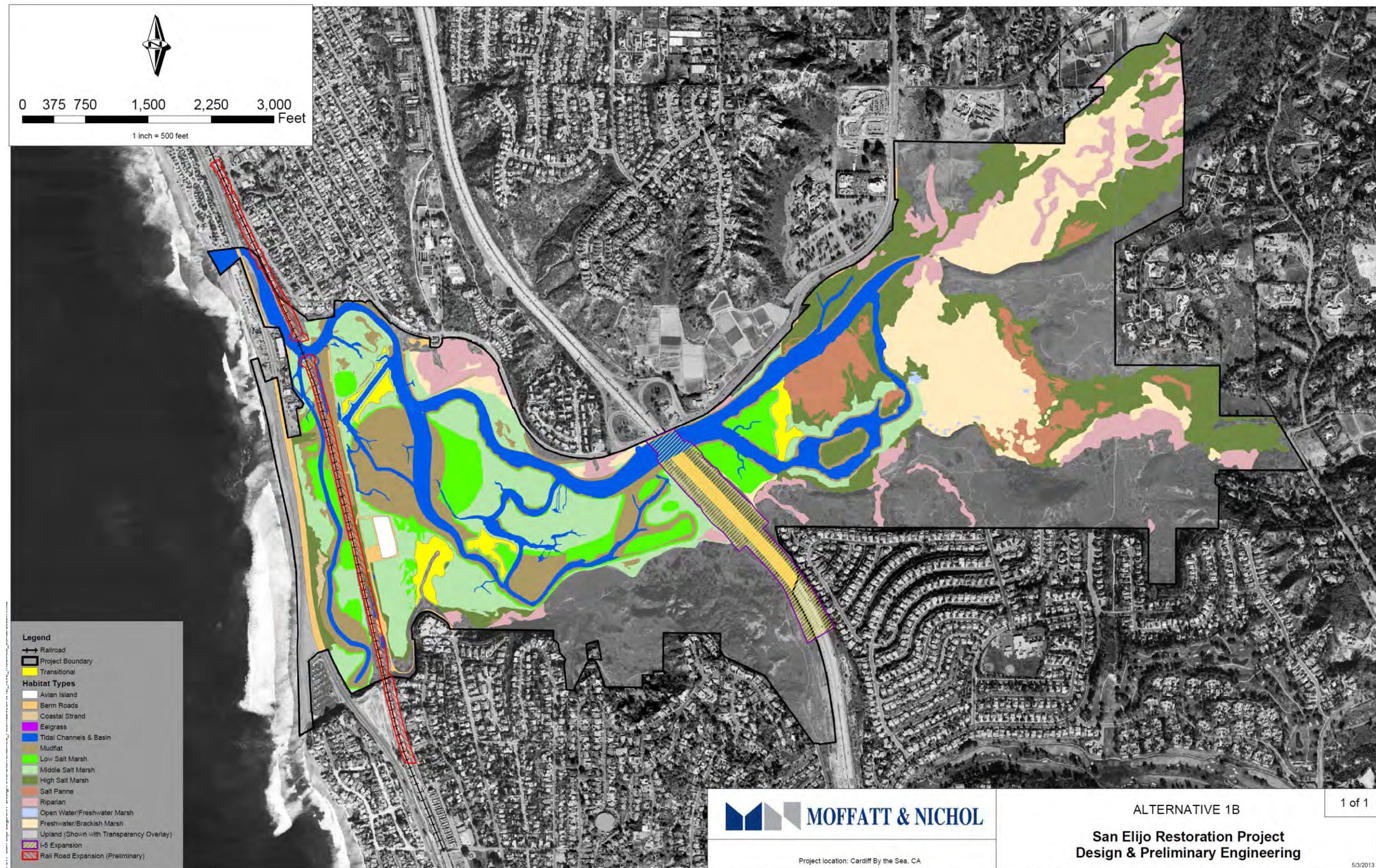


Figure 3-3: Alternative 1B

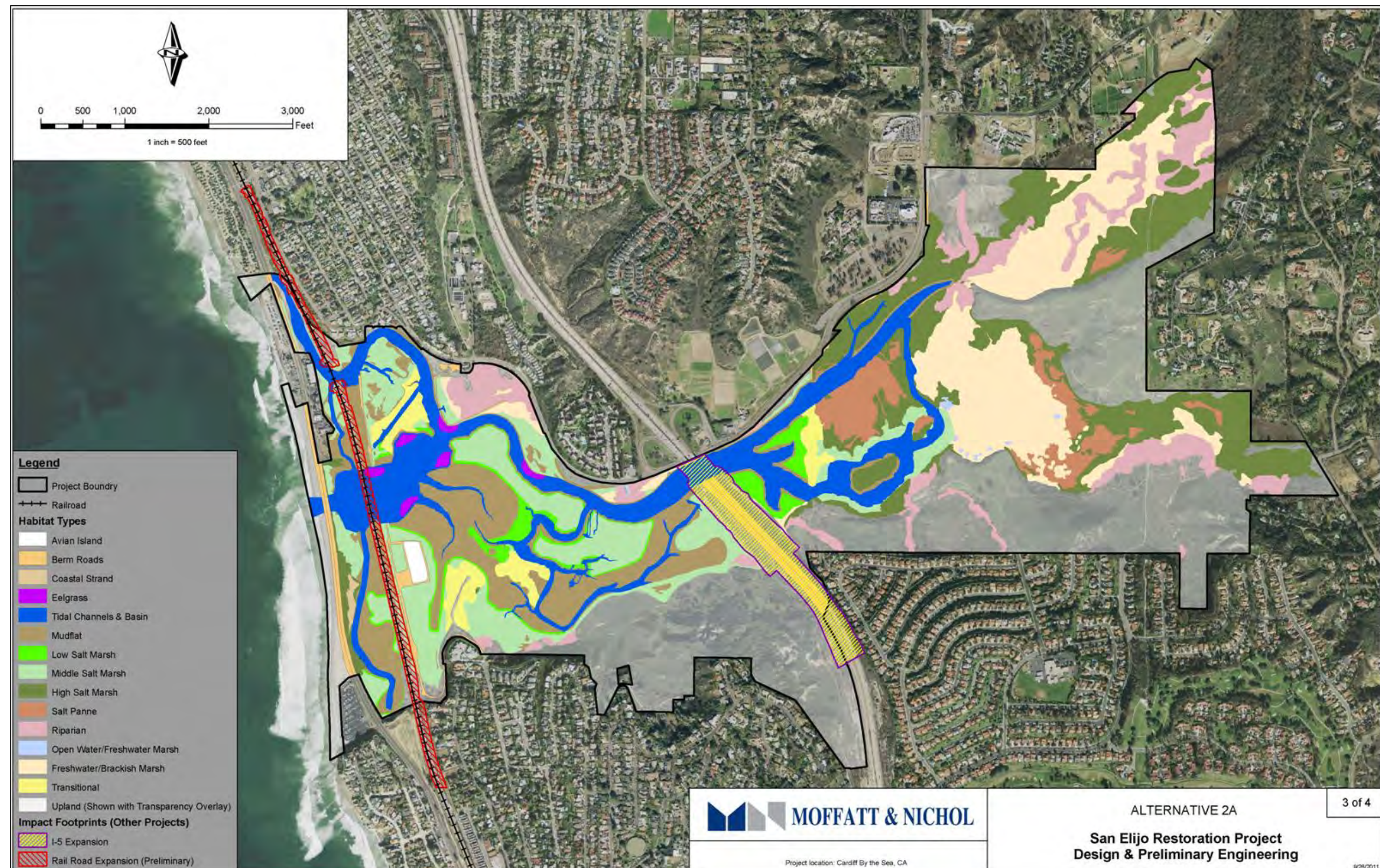


Figure 3-4: Alternative 2A

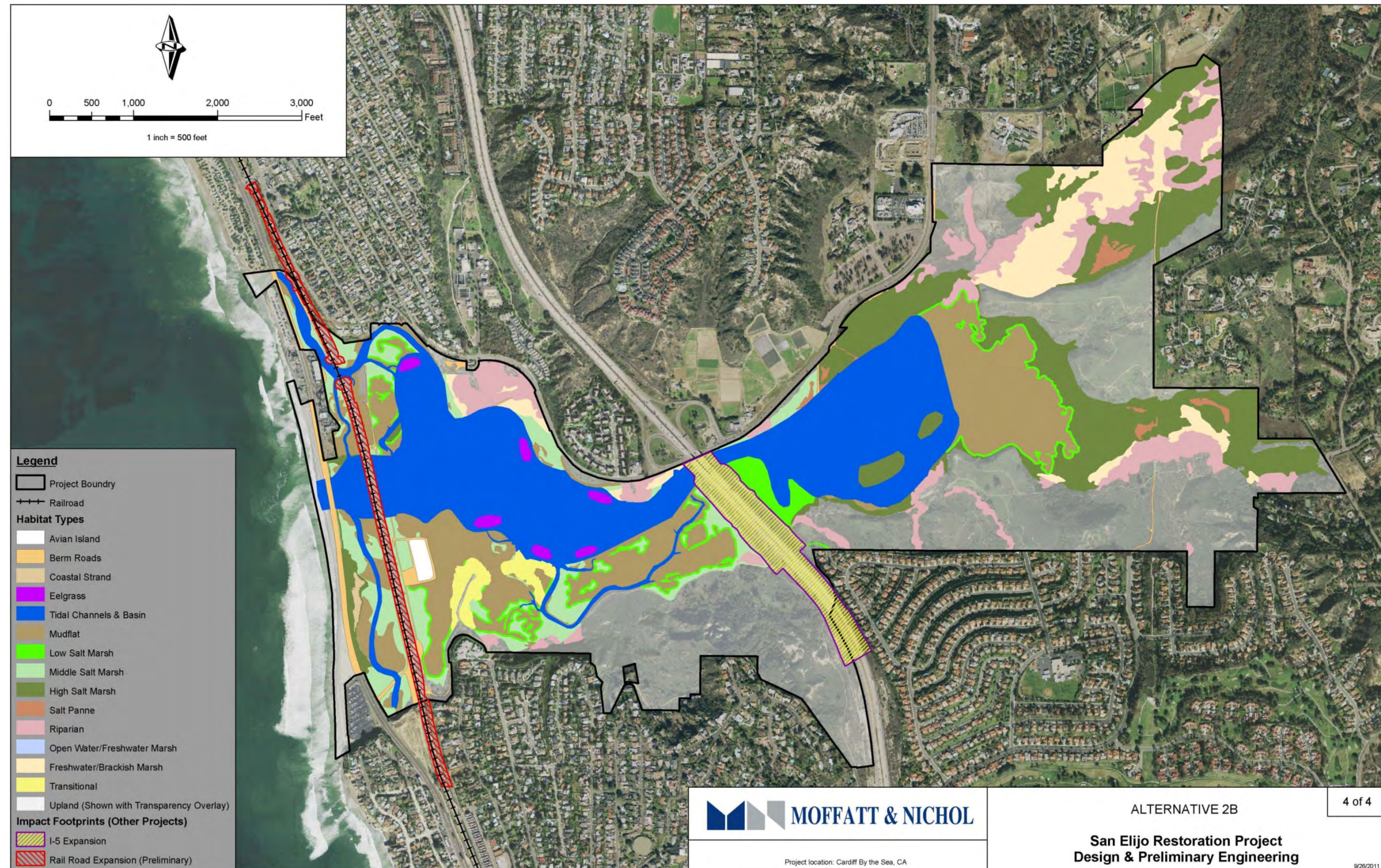


Figure 3-5: Alternative 2B

Table 3-1: Summary of Inlet and Channel Dimensions

Alternative	HW101/Inlet		Railroad Trestle		I-5 Bridge	
	Bottom Width (ft)	Invert (ft, NGVD)	Bottom Width (ft)	Invert (ft, NGVD)	Bottom Width (ft)	Depth (ft, NGVD)
Existing	105	-0.87	187	-0.87	130	0.74
1A	115	-4.0	187	-5.5	130	-6.0
1B	130	-4.0	187	-5.5	261	-6.0
2A	200	-6.5	590	-7	261	-6.5
2B	200	-6.5	590	-7	261	-6.5

3.6.1 Hwy 101 Bridge

The HW101 Bridge, shown in Figure 3-6, crosses over the existing inlet of the lagoon. The existing inlet is unstable and subject to siltation and possibly closure if not dredged on a regular basis. Although the current active inlet channel is approximately 70 feet as-built drawings and field measurements indicate the maximum opening of the HW101 bridge, from abutment to abutment, is approximately 180 feet. The lowest possible invert at the current inlet is about -4 feet NGVD due to hard bottom reef and bedrock. Accounting for side slopes and pier width, the maximum effective width of HW101 is about 160 feet at an invert elevation of -4 feet NGVD. The minimum bridge soffit elevation, indicated on the as-built drawings, is +10 feet NGVD.

Alternatives 1A and 1B retain the existing HW101 bridge, but assume significant deepening for improved hydraulics. The existing bridge may need some form of protection to prevent undermining by increased channel depths. Alternatives 2A, and 2B assume a new inlet channel location that is wider and deeper as shown in Table 3-1. The bridge optimization study confirmed the inlet channel dimensions proposed in this lagoon restoration study.



Figure 3-6: HW 101 Bridge (Existing Lagoon Inlet)

3.6.2 Railroad Bridge

The Railroad, shown in Figure 3-7, runs just east of and parallel to HW101 across the San Elijo Lagoon. Survey data of the existing railroad bridge indicate a channel width of approximately 250 feet from abutment to abutment at an elevation of +5 feet, NGVD. Assuming 3:1 (H:V) side slopes, the maximum bottom width of the existing channel under the bridge is approximately 187 feet at the dredge depth of -5.5 feet, NGVD for Alternatives 1A and 1B. The bridge is supported by 23 piers spaced at approximately 14 feet on center. The piers consist of round piles about 16 inches in diameter. Subtracting for pier widths, the effective channel width at an elevation of -5.5 feet, NGVD is approximately 161 feet. The minimum bridge soffit elevation, according to a 2007 PDC survey provided by HDR, is about +15.6 feet NGVD.

This width is significantly larger than the tidal inlet channel and most of the main channel east of the railroad bridge. Results from the tidal and flood optimization models for No Project, Alternatives 1A and 1B indicated there is no benefit to increasing the channel width below the existing railroad bridge. Alternatives 2A and 2B propose a new railroad bridge over a wide subtidal basin. The proposed channel width under the bridge would be 590 feet, significantly wider than the inlet channel and main channel throughout the lagoon.



Figure 3-7: Railroad Bridge

3.6.3 Interstate 5 Freeway Bridge

The I-5 freeway runs north to south across the San Elijo Lagoon. The I-5 Bridge crosses near the middle of the lagoon serving as the boundary between the Central and East basins of the lagoon. The I-5 Bridge also spans Manchester Avenue, as shown in Figure 3-8. The as-built plans and survey data indicate the existing channel width below the Bridge, from abutment to abutment, is approximately 155 feet at an elevation of +5 feet, NGVD. Assuming 2:1 side slopes, the existing channel bottom width in a dredged condition would be approximately 130 feet. The effective channel width modeled in RMA-2 further reduced the channel width to account for the 4-foot diameter piers supporting the bridge. The minimum bridge soffit elevation, indicated on the as-built drawings, is +31.5 feet NGVD.

Alternatives 1A and 1B retain the existing I-5 bridge, but assume significant deepening for improved hydraulics. The existing bridge may need some form of protection to prevent undermining by increased channel depths. Alternatives 2A, and 2B assume a wider and deeper channel as shown in Table 3-1. The bridge optimization study confirmed the inlet channel dimensions proposed for this restoration study.



Figure 3-8: Interstate-5 Bridge

4.0 TIDAL AND FLOOD HYDRAULICS STUDY

Numerical modeling of tidal and flood hydraulics was performed for the five alternatives to evaluate wetland hydraulics under both dry weather and wet weather (100-yr) flood conditions, and to size connections between basins to achieve desired wetland hydraulics.

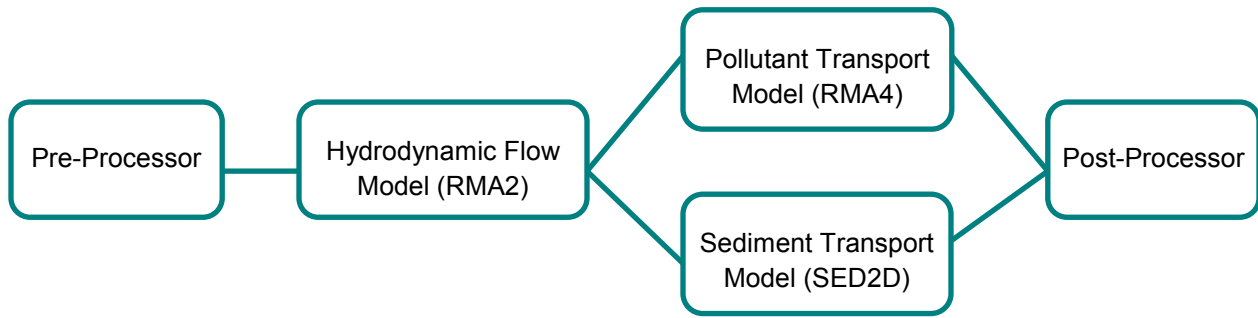
4.1 Model Selection and Description

The numerical modeling system used in this study is summarized in the following sections. The TABS2 (McAnally and Thomas, 1985) modeling system was applied to this project. TABS2 was developed by the USACE, and consists of the following components:

1. Two-dimensional, vertically-averaged finite element hydrodynamics model (RMA2);
2. Pollutant transport/water quality model (RMA4); and
3. The sediment transport model (SED2D-WES).

TABS2 is a collection of generalized computer programs and pre- and post-processor utility codes integrated into a numerical modeling system for studying 2-D depth-averaged hydrodynamics, transport and sedimentation problems in rivers, reservoirs, bays, and estuaries. The finite element method provides a means of obtaining an approximate solution to a system of governing equations by dividing the area of interest into smaller sub-areas called elements. Time-varying partial differential equations are transformed into finite element form and then solved in a global matrix system for the modeled area of interest. The solution is smooth across each element and continuous over the computational area. This modeling system is capable of simulating tidal wetting and drying of marsh and intertidal areas of the estuarine system.

A schematic representation of the system is shown below. TABS2 can be used either as a stand-alone solution technique or as a step in the hybrid modeling approach. RMA2 calculates water surface elevations and current patterns which are input to the pollutant transport and sediment transport models. Existing and proposed wetland geometry can be analyzed to determine the impact of project designs on flow, circulation (this study), salinity and water quality (a subsequent study) and sedimentation (another subsequent study) on the estuarial system. The three models listed above are solved by the finite element method using Galerkin weighted residuals.



TABS2 Schematic

The hydrodynamic model simulates 2-D flow in rivers and estuaries by solving the depth-averaged Navier Stokes equations for flow velocity and water depth. The equations account for friction losses, eddy viscosity, Coriolis forces and surface wind stresses. The general governing equations are:

$$\frac{\partial h}{\partial t} + \frac{\partial(hu)}{\partial x} + \frac{\partial(hv)}{\partial y} = 0$$

$$h \frac{\partial u}{\partial t} + uh \frac{\partial u}{\partial x} + vh \frac{\partial u}{\partial y} + gh \frac{\partial a}{\partial x} + gh \frac{\partial h}{\partial x} - h \frac{\varepsilon_{xx}}{\rho} \frac{\partial^2 u}{\partial x^2} - h \frac{\varepsilon_{xy}}{\rho} \frac{\partial^2 u}{\partial y^2} + S_{f_x} + \tau_x = 0$$

$$h \frac{\partial v}{\partial t} + uh \frac{\partial v}{\partial x} + vh \frac{\partial v}{\partial y} + gh \frac{\partial a}{\partial y} + gh \frac{\partial h}{\partial y} - h \frac{\varepsilon_{yx}}{\rho} \frac{\partial^2 v}{\partial x^2} - h \frac{\varepsilon_{yy}}{\rho} \frac{\partial^2 v}{\partial y^2} + S_{f_y} + \tau_y = 0$$

where:

u, v = x and y velocity components

t = time

h = water depth

a = bottom elevation

S_{f_x} = bottom friction loss term in x-direction

S_{f_y} = bottom friction loss term in y-direction

τ_x = wind and Coriolis stresses in x-direction

τ_y = wind and Coriolis stresses in y-direction

ε_{xx} = normal eddy viscosity in the x-direction on x-axis plane

ε_{xy} = tangential eddy viscosity in the x-direction on y-axis plane

ε_{yx} = tangential eddy viscosity in the y-direction on x-axis plane

ε_{yy} = normal eddy viscosity in the y-direction on y-axis plane

Wind stress is computed using the following formula:

$$\tau_s = 3.8 \cdot 10^{-6} W^2$$

where

τ_s is wind stress (lb/ft/sec²) on the water surface, and

W is the wind speed in miles per hour at 10 meters (33 feet) above the water surface.

4.2 Model Setup

The setup for the tidal and flood hydraulic models for existing conditions and all alternatives included determination of the model area, bathymetry, wetland habitat area, mesh selection, and boundary conditions. For this study, a RMA2 model was previously created by the USACE (2006) for this site based on the 1990 topographic survey (Towill Inc. 2009). That RMA2 model setup was modified to include all areas of interest and potential tidal and/or storm flow influence, and to contain the most current topographic and bathymetry data.

The horizontal coordinate system for the modeling work is North American Datum (NAD) 83, California state plan zone 6, and the vertical datum is National Geodetic Vertical Datum (NGVD) 1929, which is equivalent to Mean Sea Level (MSL) at that time. As sea level has risen since 1929, NGVD is lower than existing MSL by approximately 0.44 feet. The reason that the vertical datum is NGVD is that the existing topographic survey of the site is referenced to NGVD. Both horizontal and vertical units are in feet.

4.2.1 Model Area

The numerical model covers the nearshore ocean and the area below the +12.9 foot NGVD (15-foot NAVD) contour line of West Basin, Central Basin, and East Basin as shown in Figure 4-1. The original USACE model, which only covers the tidally-influenced area approximately below the +6.5 foot contour line, was raised to the +12.9 foot contour line to contain water levels during the 100-year flood condition.

The ocean boundary is approximately one mile from the shoreline. The side boundaries of the offshore area are approximately one mile north and two miles south from the existing inlet location, so the offshore ocean area will remain the same for all alternatives, regardless of the location of the tidal inlet.



Figure 4-1: Numerical Modeling Area

4.2.2 Bathymetry

The ocean bathymetry used in the model is the same data used in model meshes created by the USACE (2006) for this location. The USACE created the mesh of the lagoon area based on the 1990 topographic survey (Towill Inc. 1990). The 1990 survey only covers the area above +1.8 feet NGVD as the area below +1.8 feet was under water at the time of the survey and not measured. To fill the data gap below +1.8 feet NGVD, measurements of channel cross-sections were conducted in October 2000 in the Lagoon by Dr. Terrell (Terrell et. al. 2009) and Coastal Environments (2000). Electronic data of these cross-sections were provided through the SELC.

A recent survey of the San Elijo Lagoon was conducted by KDM Meridian in 2011 for the San Elijo Lagoon Conservancy and included aerial photogrammetric mapping augmented with a bathymetric survey of the main channel and tributaries. This data set provides the existing surface both above and below the water level for the entire model area east of HW 101. The RMA2 models for all project alternatives were updated to represent the 2011 survey and bathymetry data within the Lagoon. The ocean bathymetry was beyond the limits of the KDM Meridian survey and therefore was not updated. The ocean bathymetry data used in the model will not affect results for two reasons. One reason is that changes in ocean bathymetry mostly

are confined to nearshore areas with little or no change in offshore bathymetry. The second reason is that modeling results are not sensitive to small changes in offshore bathymetry because the relatively large ocean depths result in little or no energy loss during fluctuating sea levels. The No Project and Alternative 1A models are most sensitive to the updated bathymetry since there is little or no grading proposed for these alternatives. The 2011 survey indicates the ground surface throughout most of the lagoon is about 0.5 to 1 foot higher when compared to the 1990 topography.

Figure 4-2 shows the existing bathymetry of the entire modeling area under the existing condition. Figure 4-3 shows only the existing Lagoon bathymetry.

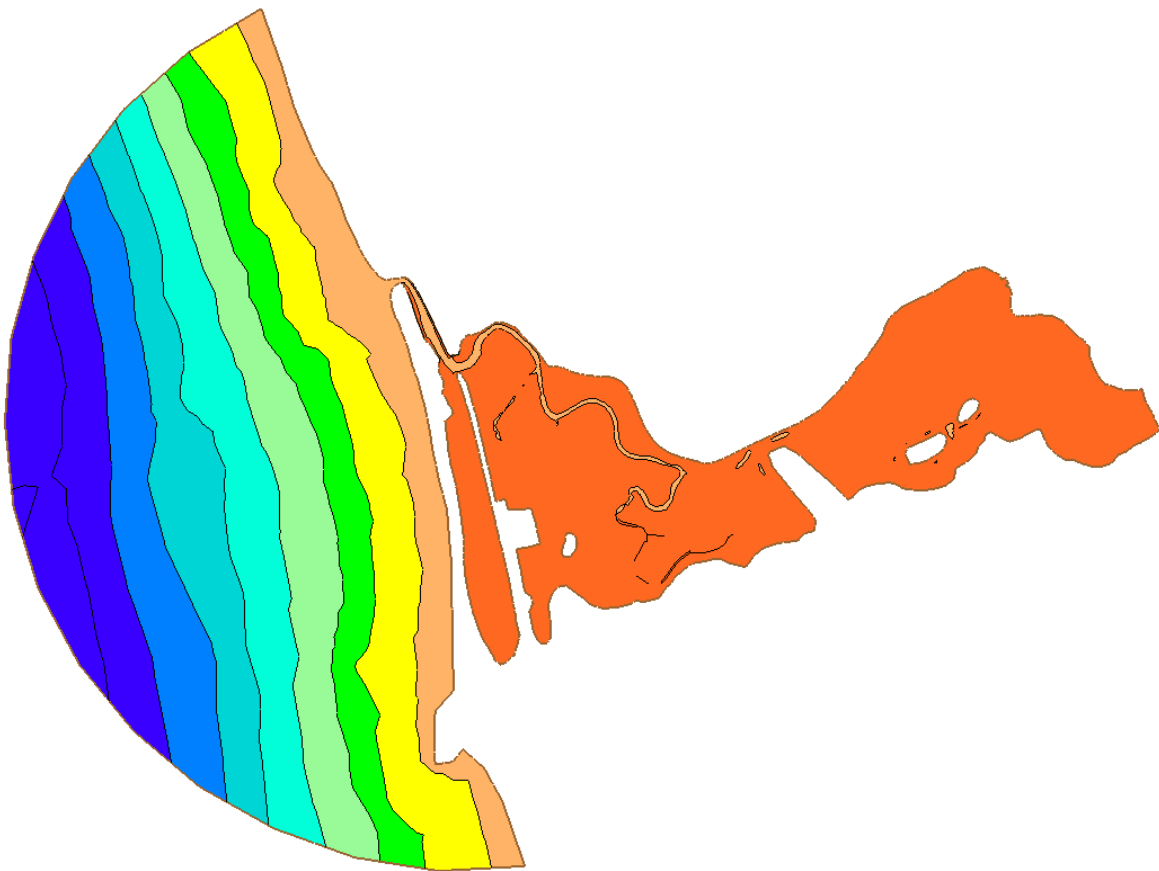


Figure 4-2: Existing Bathymetry for the Entire Modeling Area

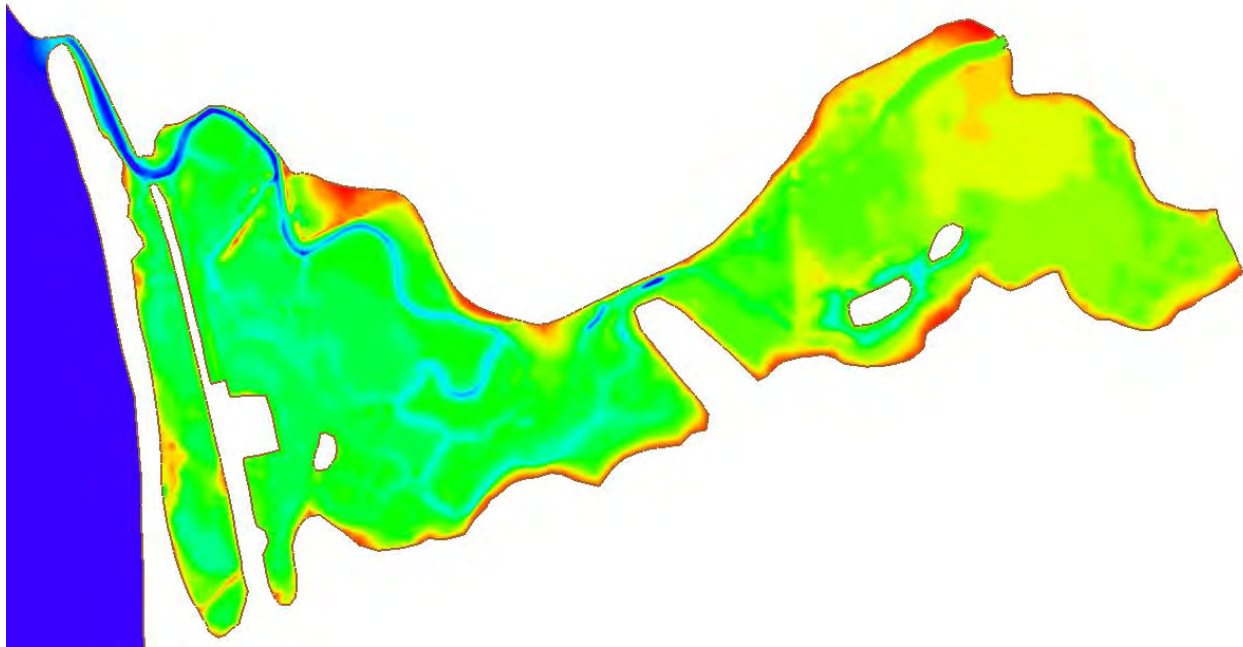


Figure 4-3: Existing Lagoon Bathymetry

4.2.3 Finite Element Mesh

The RMA2 modeling system requires that the estuarial system be represented by a network of nodal points and elements, points defined by coordinates in the horizontal plane and water depth, and areas made up by connecting these adjacent points, respectively. Nodes can be connected to form 1- and 2-D elements, having from two to four nodes. The resulting nodal/element network is commonly called a finite element mesh and provides a computerized representation of the estuarial geometry and bathymetry.

It is noted that evaluations discussed herein correspond to 2-D analyses. Each alternative was sufficiently dissimilar that a unique finite element mesh was developed to reflect the bathymetry and wetland boundaries for each alternative considered.

The two important aspects to consider when designing a finite element mesh are (1) determining the level of detail necessary to adequately represent the estuary, and (2) determining the extent or coverage of the mesh. Accordingly, the bathymetric features of the estuary generally dictate the level of detail appropriate for each mesh. These concerns present trade-offs for the modeler to consider. Too much detail can lead the model to run slowly or even become unstable and “crash.” Too little detail renders the results less useful. For this project, a balance was achieved with a stable and efficient model that yields the level of detail required for planning. The model described in this section is numerically robust and capable of simulating tidal elevations, flows, and constituent transport with reasonable resolution.

There are several factors used to decide the aerial extent of each mesh. First, it is desirable to extend mesh open boundaries to areas which are sufficiently distant from the proposed areas of

change so as to be unaffected by that change. Additionally, mesh boundaries must be located along sections where conditions can reasonably be measured and described to the model. Finally, mesh boundaries can be extended to an area where conditions have been previously collected to eliminate the need to interpolate between the boundary conditions from other locations.

The finite element meshes for the calibration and model runs for alternatives are shown in Figure 4-4 through Figure 4-8. Each mesh contains a section of ocean sufficiently large to eliminate potential model boundary effects. The wetland portion of the mesh is bounded by Highway 101, Manchester Avenue and dry land considered to be at the outermost extents of the flood influence. The nearshore mesh is the same for each alternative.

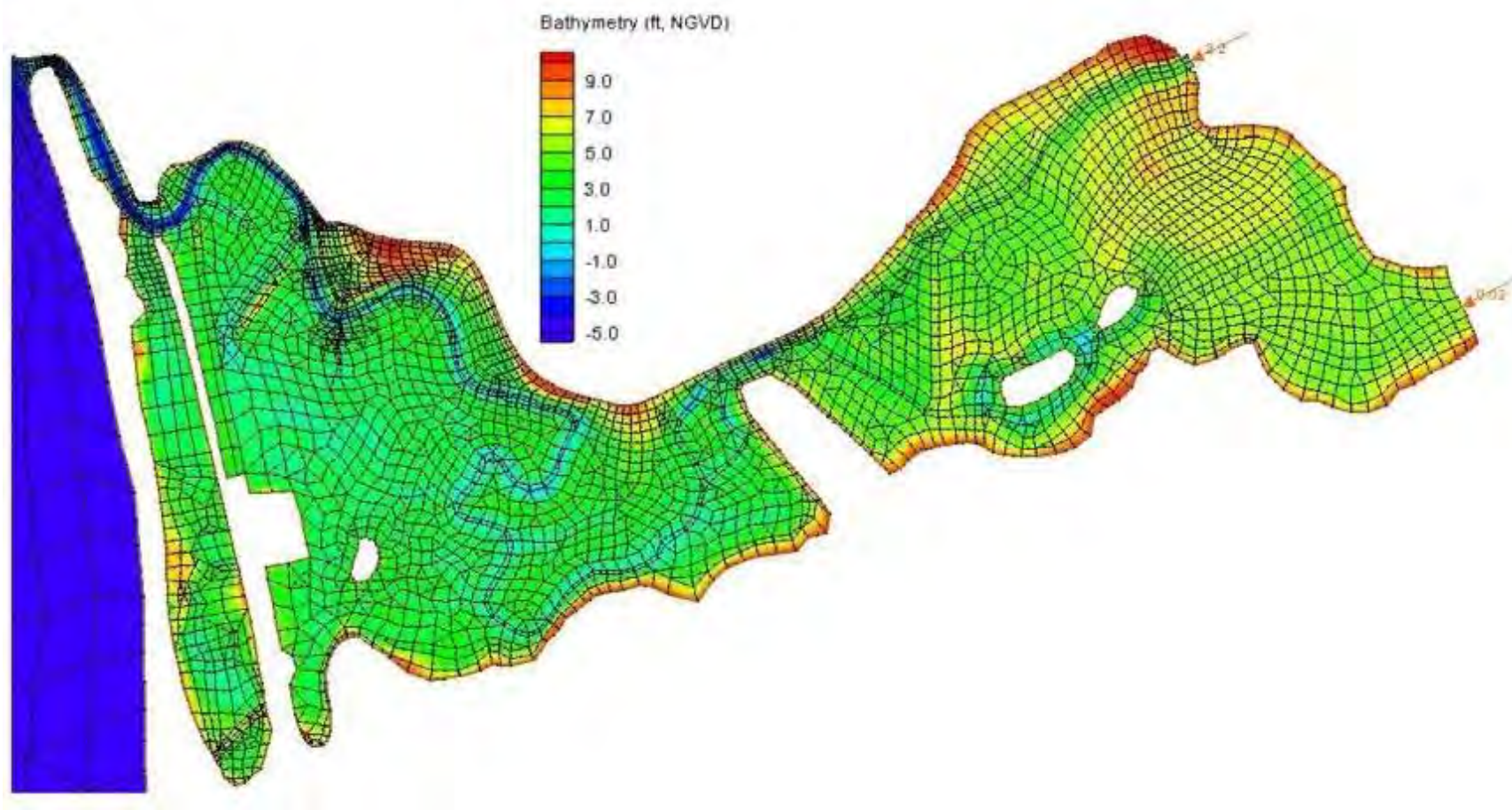


Figure 4-4: RMA2 Model Mesh for Existing Conditions

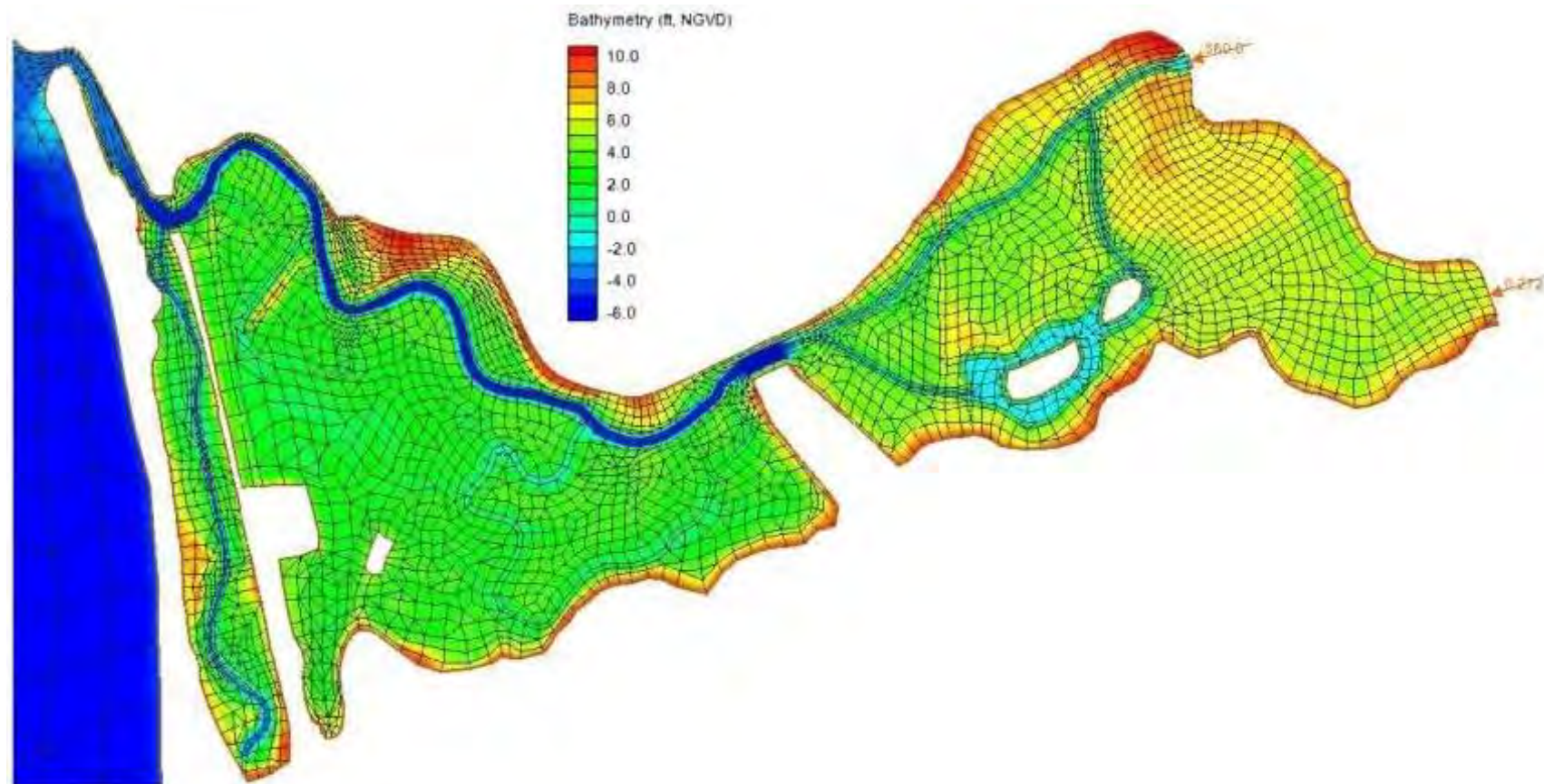


Figure 4-5: RMA2 Modeling Mesh for Alternative 1A

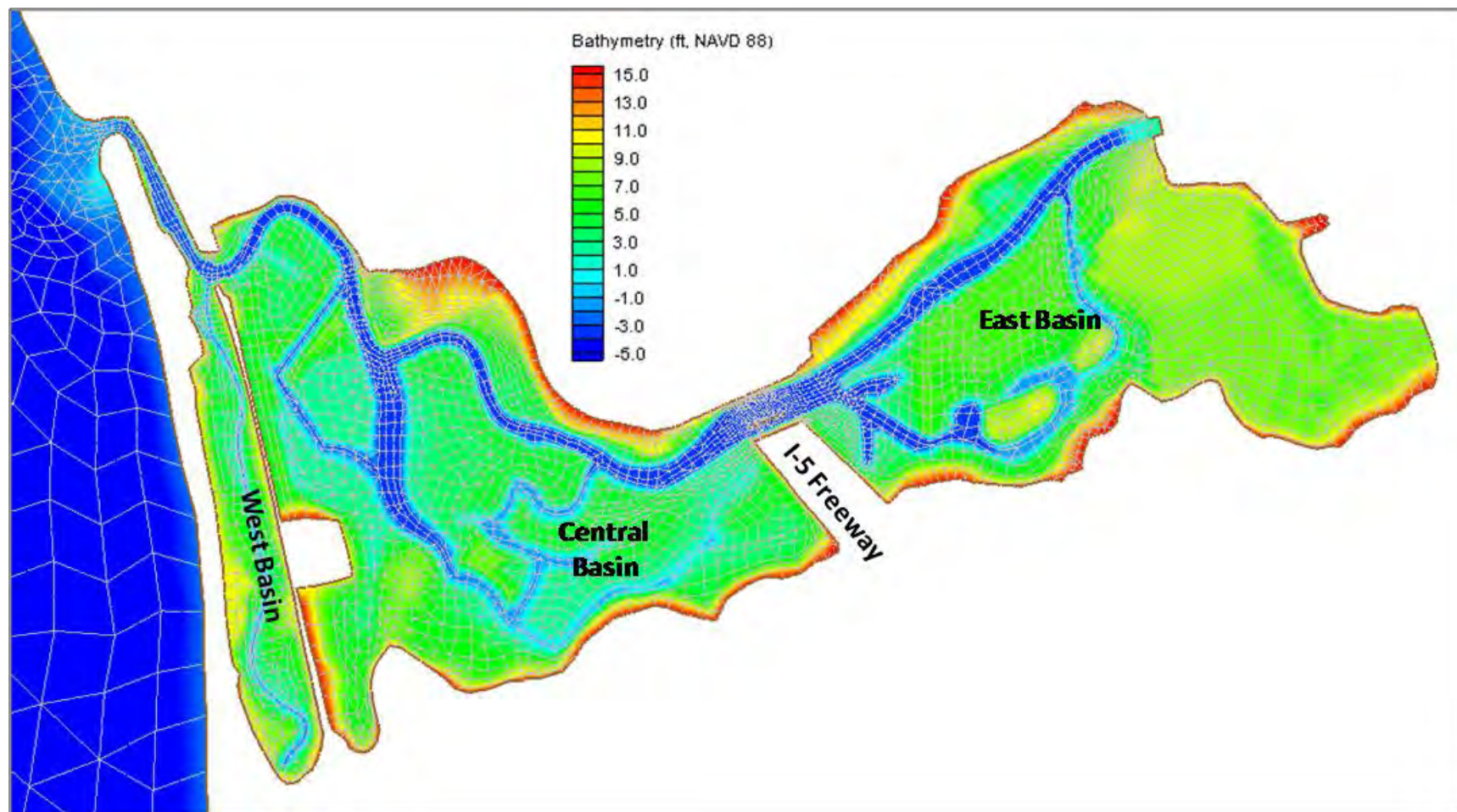


Figure 4-6: RMA2 Modeling Mesh for Alternative 1B

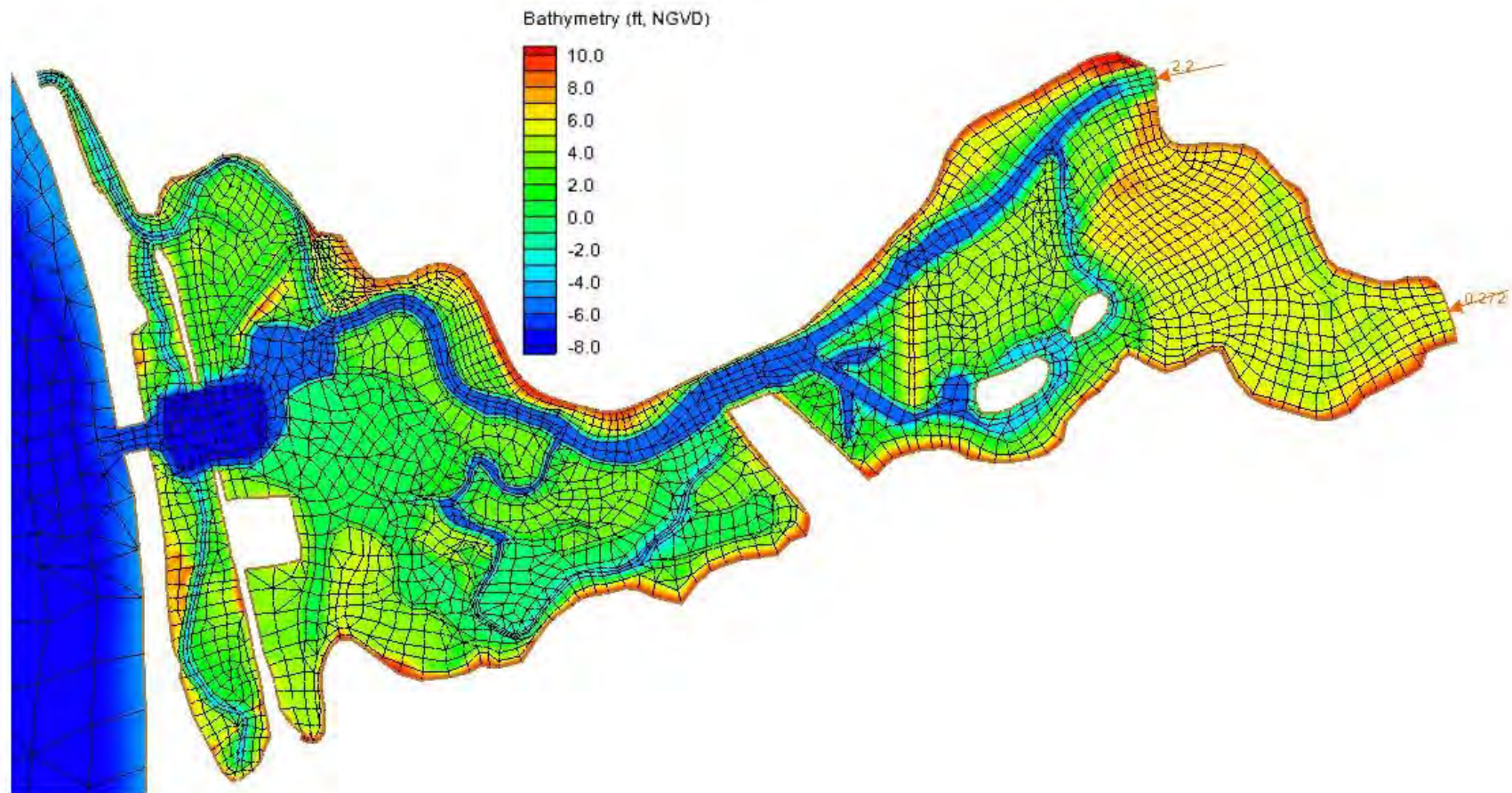


Figure 4-7: RMA2 Modeling Mesh for Alternative 2A

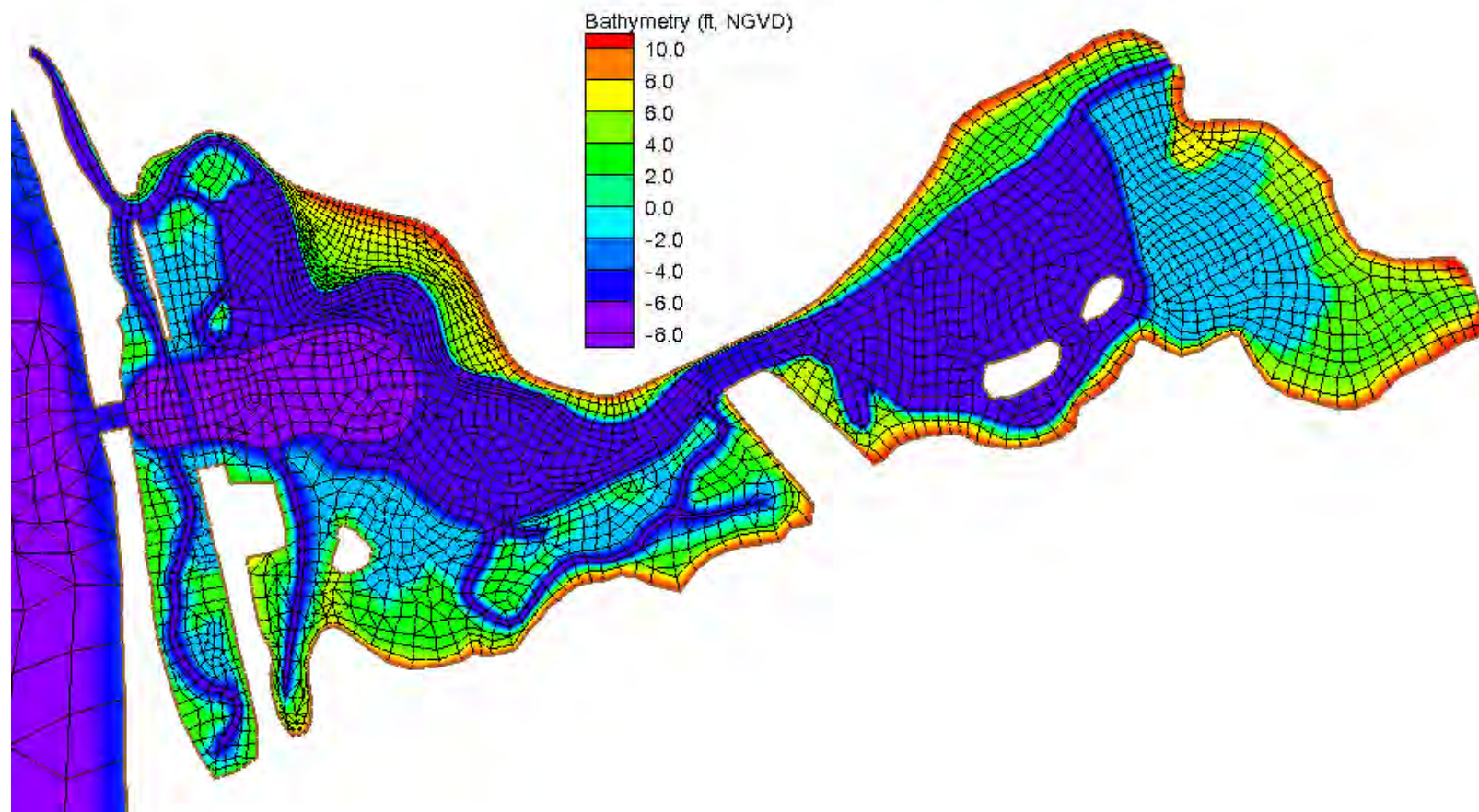


Figure 4-8: RMA2 Modeling Mesh for Alternative 2B

The entire modeling area, approximately 2.54 square miles, is represented as a finite element mesh consisting of elements and nodes detailed in Table 4-1.

Table 4-1: Model Mesh Elements and Nodes

Alternative	Number of Elements	Number of Nodes
Existing Conditions	3,790	11,114
Alternative 1A	4,654	13,280
Alternative 1B	4,663	13,017
Alternative 2A	4,339	12,379
Alternative 2B	4,037	11,710

4.2.4 Boundary Conditions

4.2.4.1 Tides

Since there are no tide stations at San Elijo Lagoon, the nearest La Jolla gage (National Oceanic and Atmospheric Administration Station ID: 9410230) was used to represent the ocean tide at the project site as shown in Table 4-4. The diurnal tide range is approximately 5.33 feet Mean Lower Low Water, MLLW, to Mean Higher High Water, MHHW, and MSL is at +2.73 feet MLLW. Water level data records provide astronomical tides and other components including barometric pressure tide, wind setup, seiche, and the El Nino Southern Oscillation. Tidal variations can be resolved into a number of sinusoidal components having discrete periods. The longest significant periods, called tidal epochs, are approximately 19 years. In addition, seasonal variations in MSL can reach amplitudes of 0.5 feet in some areas. Superimposed on this cycle is a 4.4-year variation in the MSL that may increase the amplitude by as much as 0.25 feet. Water level gage records are typically analyzed over a tidal epoch to account for these variations and to obtain statistical water level information (e.g., MLLW and MHHW).

Table 4-2: Recorded Water Levels at La Jolla (1983-2001 Tidal Epoch)

Description	Elevation (feet, MLLW)	Elevation (feet, NGVD)
Extreme High Water (11/13/1997)	7.65	5.35
Mean Higher High Water (MHHW)	5.33	3.03
Mean High Water (MHW)	4.60	2.30
Mean Tidal Level (MTL)	2.75	0.46
Mean Sea Level (MSL)	2.73	0.44
National Geodetic Vertical Datum 1929 (NGVD)	2.30	0.00
Mean Low Water (MLW)	0.91	-1.39
North America Vertical Datum 1988 (NAVD)	0.19	-2.11
Mean Lower Low Water (MLLW)	0.00	-2.30
Extreme Low Water (12/17/33)	-2.87	-5.16

4.2.4.2 Modeling Tidal Series

The tide series used for modeling was a representative period from November 7-21, 2008. Modeling long-term hydrologic conditions is typically done using a synthetic (artificially-created) tide series that represents average spring tide conditions over the most recent 19-year tidal epoch, referred to as a Tidal Epoch Analysis (TEA) tide series. The benefit of using a statistical tide is that the long-term condition can be modeled over a shorter time period with less computation time.

The most recent previous modeling of this site was done by the USACE without the benefit of preparing a TEA tide, and significant effort (beyond the scope of this study) is required to prepare a new TEA tide for this site. Therefore, a real tide series was used that matched average spring tide data available from National Oceanic and Atmospheric Administration (2009).

Not using a statistical TEA tide for modeling is not a serious information gap. To address this potential shortcoming, the modeler evaluated existing tide data from NOAA for San Diego at Scripp's Pier (NOAA 2011). NOAA began publishing spring high and spring low tidal elevations of all tidal cycles in January of 2008. The modeler averaged the spring high and spring low tidal elevations of all tidal cycles from January of 2008 through July of 2011 (42 months), then examined the existing data to identify a real two week tidal cycle that matched them. Tides during the period of June 7 through June 21, 2011 reached nearly the exact same spring high and spring low tidal elevations of NOAA's longer 42-month record. Also, the average tidal elevation of that June 7 through June 21, 2011 period compared with the average tidal elevation of the 19-year tidal epoch and was within 0.01 foot. Therefore, the modeler concluded that tides during the period of June 7 through June 21, 2011 sufficiently matched long-term tides at the site, and use of this record poses no implications on habitat designs and analyses. The modeling tide includes both spring and neap tidal ranges as shown in Figure 4-9. This tidal series is used in the tidal hydraulics modeling of this study.

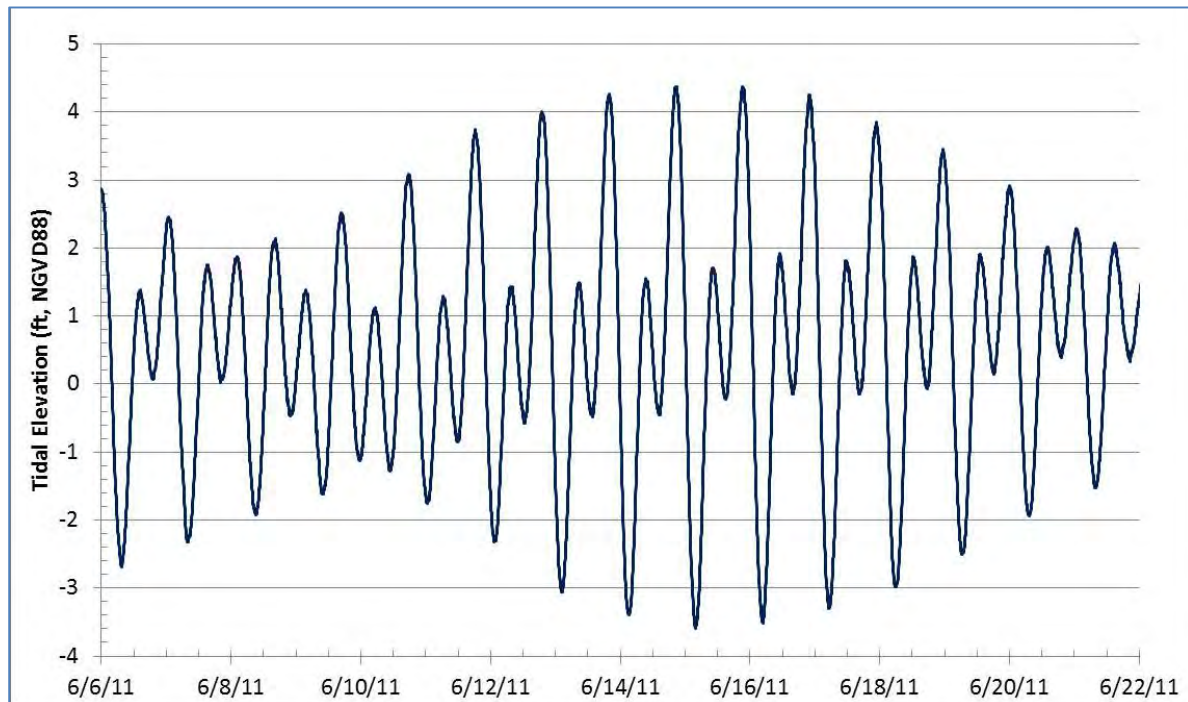


Figure 4-9: Modeling Tidal Series

4.2.4.3 Recorded Highest Tidal Series

In Southern California, the winter riverine storm season coincides with the season of the winter King Tides. King Tides occur from two to four times a year when the gravitational forces of the sun, the Earth, and a full moon are in alignment. As a consequence, it is recommended that fluvial hydraulic modeling with the unsteady model RMA2 be conducted with a design sea level value of the highest observed ocean water level of 5.4 feet, NGVD because this elevation is very close to the 100-yr extreme tidal elevation of 5.3 feet. This was done for Caltrans as part of a separate subsequent study called the Hydraulic Study of I-5 Bridge over San Elijo Lagoon (M&N 2014) that is discussed later in this report. The simultaneous occurrence a peak 100-year fluvial flood event and the 100-year extreme tidal elevation provides a reasonable and conservative boundary condition. Figure 4-10 shows the recorded tidal elevations (NOAA 2013) during the highest observed tidal event that were used in the I-5 Bridge Hydraulic Study (M&N 2014) to assess the 100-year storm water levels.

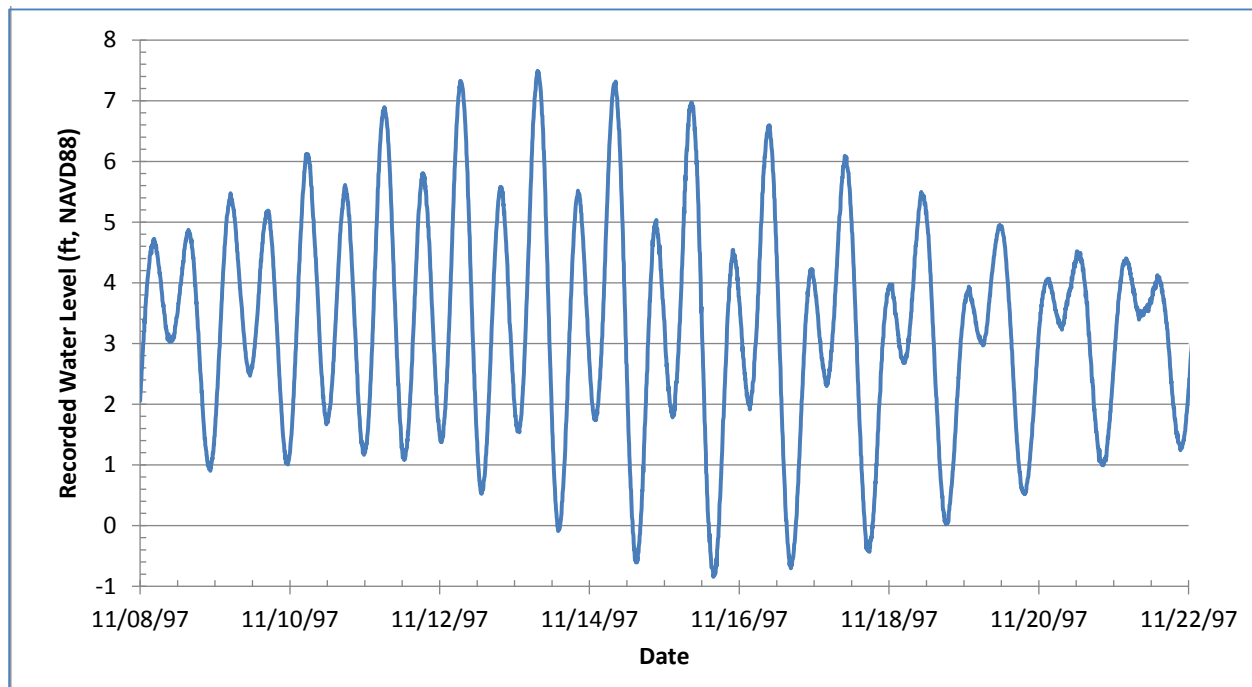


Figure 4-10: Recorded Highest Tidal Series

4.2.4.4 Flood Flows from Creeks

San Elijo Lagoon is the estuary of both Escondido and La Orilla Creeks. The Escondido Creek watershed extends approximately 28 miles from its headwaters in Bear Valley to the San Elijo Lagoon before discharging into the Pacific Ocean. The watershed covers approximately 54,112 acres in area and is long and narrow. La Orilla Creek is a very short stream that has only a marginal contribution of flood and sediment discharges compared to Escondido Creek. In the past, these creeks were considered to be ephemeral, but in the last few decades low flows from urbanization are present all year long.

The SELC installed and has managed a network of stream gauges in the Carlsbad Hydrology Unit since 2004, which is partially supported by the San Diego Regional Water Quality Control Board (SDRWQCB) and the California State Coastal Conservancy (CSCC). The gage on Escondido Creek is located at Camino del Norte Bridge. A 15-minute interval data set for the period from November 4, 2004 through January 2010 was provided by the SELC. A period of the data set for January 2008 was used in RMA2 numerical model verification. A storm event with a peak flow rate of 1,140 cubic feet per second (cfs) in January 2008 was also selected to represent a 2-yr event for analyzing salinity and water quality modeling of bacteria in a subsequent study. However, the period of the recorded flows is insufficient for statistically generating 50 and 100-yr return period flood flows for storm flow modeling.

A statistical analysis was performed by Exponent Inc. (2000) to determine 50- and 100-year flood flows based on data from a neighboring stream gage on Las Flores Creek near Oceanside Harbor, as the stream gage record for Escondido Creek is too short to generate statistics and

no stream gage exists on La Orilla Creek. The 100-year peak flood was determined to be 21,000 cubic feet per second (cfs) for Escondido Creek, which is the same as the flood flow rate used by FEMA for the National Flood Insurance Program. The watershed area of La Orilla Creek is about 10 percent of that for Escondido Creek; therefore the combined peak flow from both creeks is estimated to be 23,255 cfs. This value was used by Dokken Engineering (2007) in their location hydraulic study for the I-5 Bridge. A daily hydrograph was developed by Exponent (2000) and was raised to the peak flow rate of 23,255 cfs to represent storm flood flows into the Lagoon, shown in Figure 4-11.

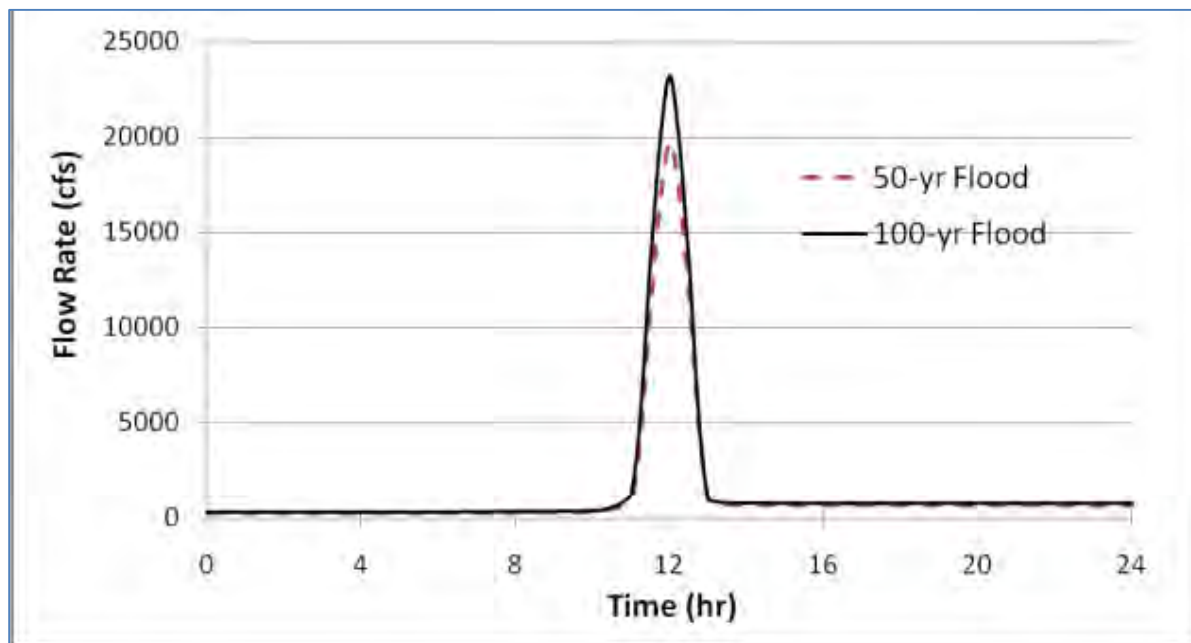


Figure 4-11: Flood Hydrographs

Table 4-3 shows the model simulations necessary to (1) perform the RMA2 model calibration, (2) predict water surface elevations in the Lagoon under both tidal and flood flow conditions, and (3) predict velocity in the tidal inlet for inlet stability analyses. The extreme tidal series discussed in Section 4.2.4.3 was used in the RMA2 modeling to provide the extreme maximum water surface elevation under the 100-year storm event in the Lagoon for flood protection assessment.

Analyses were also performed on an ad hoc basis at the request of the Stakeholder group to assess whether a flood training dike is necessary downstream of I-5 Bridge in the Central Basin to reduce potential scour under the flood event. Model results were useful to determine that the flood training is not necessary and it was eliminated as a project component. No formal additional reporting of that effort was prepared, other than inclusion of the model runs in the table on the following page.

Table 4-3: Suite of RMA2 Numerical Hydrodynamic Simulations

Alternative	Flood Flow	Tide Condition	Purpose
Existing	N/A	Measured	RMA2 Calibration
	None	Actual	Tidal ranges Inlet velocity Inundation frequency
	100-year	Highest Measured	Flood Elevations
1A	None	Actual	Tidal ranges Inlet velocity Inundation frequency
	100-year	Highest Measured	Flood Elevations
1B	None	Actual	Tidal ranges Inlet velocity Inundation frequency
	100-year	Highest Measured	Flood elevations
2A	None	Actual	Tidal ranges Inlet velocity Inundation frequency
	100-year	Highest Measured	Flood Elevations
2B	None	Actual	Tidal ranges Inlet velocity Inundation frequency
	100-year	Highest Measured	Flood Elevations

4.3 Model Calibration for Existing Tidal Conditions

RMA2 calibration involves matching model predictions with measured data by selecting appropriate input variable values (e.g., Manning's roughness coefficient (n), peclot numbers, and marsh porosity) to the model. The model was calibrated using measured tides for the existing tidal hydraulic system of San Elijo Lagoon. Tidal elevations measured at both the railroad trestle bridge (RR) and I-5 Bridge (I-5) in the late summer of 2002 were used for the calibration. The calibration data were provided by the USACE (2006), although the data were originally collected by the San Elijo Lagoon Conservancy (2002). The gage locations are shown in Figure 4-12. Verification could not be performed due to the short calibration data period.

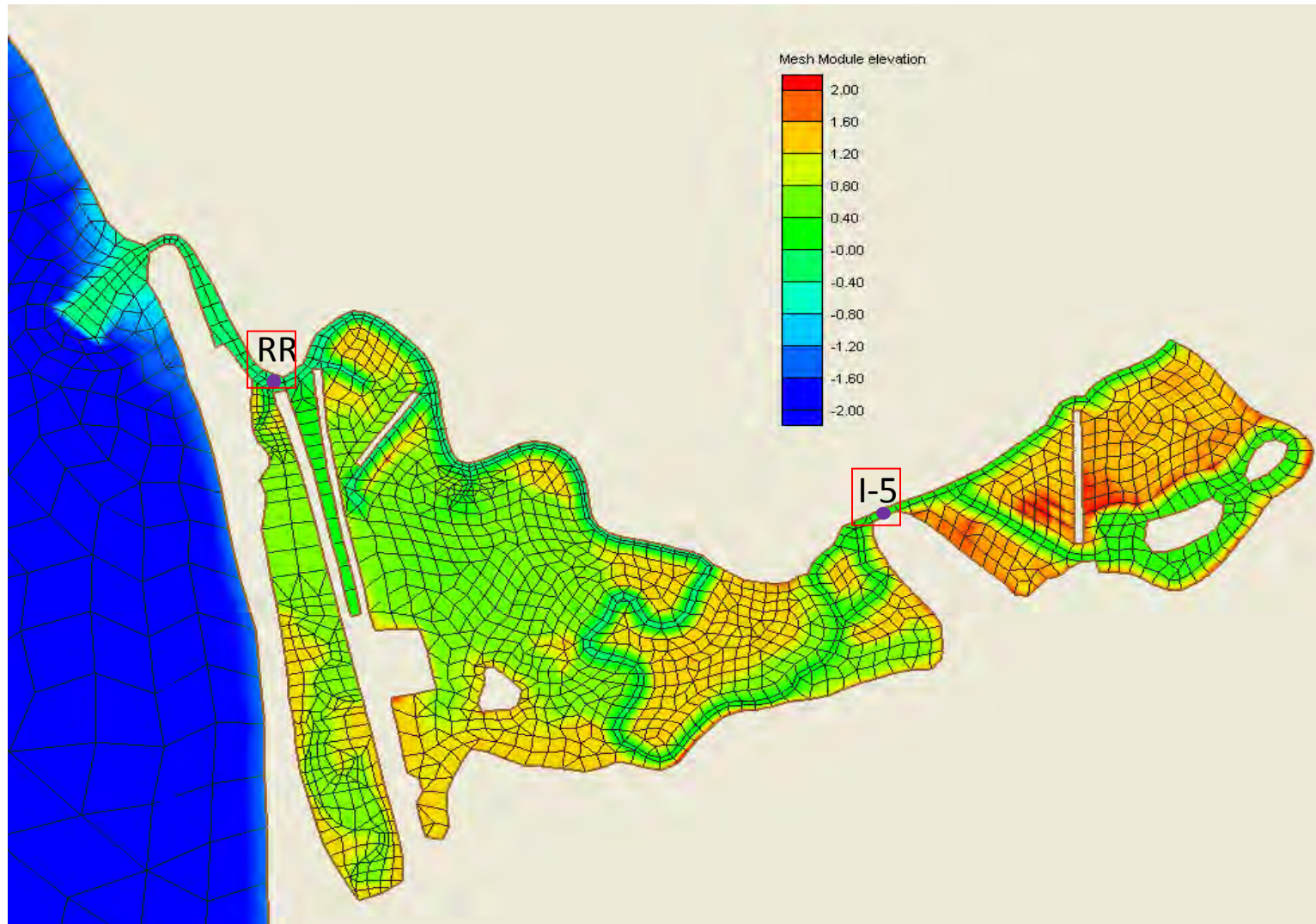


Figure 4-12: RMA2 Model Calibration Gage Locations

4.3.1 Model Setup for Calibration

The RMA2 User's Manual recommends ranges of values for Manning's roughness coefficient (n) and eddy viscosity to be used in the model (U.S. Army Corps of Engineers WES, 2009). The value of Manning's roughness coefficient (n) is a function of the physics of the hydraulic system and represents the roughness of the channel bed. As discussed in Chaudhry (1993), values can range from 0.011 to 0.075 or higher for natural rivers and estuaries. Relatively high values (0.04 to 0.05) are specified for rough surfaces, such as channels with cobbles or large boulders. Mid-range values (0.03) represent clean and straight natural streams. Low values (0.013 to 0.02) are specified for smooth surfaces, such as concrete, cement, wood, or gunite. Values of Manning's roughness coefficient (n) used for this analysis are in the middle range of the recommended values.

The modeling grid size depends on and is limited by the Peclet number and eddy viscosity. The Peclet number is defined as,

$$\frac{\rho V \Delta X}{E_{ij}}$$

in which ρ , V , ΔX , and E_{ij} are the water density, velocity, grid size and eddy viscosity, respectively. In order for the solution to be stable, the Peclet number has to be less than 50. The Peclet number can be reduced by increasing the mesh density or by increasing the eddy viscosity. However, it is unrealistic and time-consuming to perform this modeling with a very fine grid. Eddy viscosity is another variable often specified in modeling. It represents the degree of turbulence in the flow. A higher value represents greater turbulence, while a low value suggests less turbulence. The modeling approach can either be based on use of the Peclet number or eddy viscosity. This modeling was based on specifying the Peclet number to maximize model stability and to minimize "crashing." Calibration parameters were adjusted until model results approximated field measurements. The resulting calibration parameters are presented in Table 4-4.

Table 4-4: Setup Values For Model Calibration

Model Area	Manning's Roughness Coefficient (n)	Peclet Number
Offshore Area	0.025	40
Tidal Inlet and Channels	0.020	10
Mudflat	0.025	0.1
Low Marsh	0.030	0.1
High Marsh	0.035	0.1
Riparian	0.040	0.1
Upland	0.045	0.1

The time step is another very important parameter in the modeling. Sensitivity tests were conducted and results showed that the RMA2 model becomes unstable with increasing the time step, if the tidal wetting and drying processes are considered. Therefore, a relatively fine time step of 0.1 hour was used in order for the solution to be stable and to reflect the dynamic tidal series and flood flow hydrograph.

4.3.2 Model Sensitivity

Sensitivity tests were performed to evaluate the robustness of the model during the model calibration process by varying the calibration parameters. The calibration parameters for RMA2 model include roughness (Manning's coefficient), Peclet number (Eddy viscosity), and Marsh Porosity.

- The model is not very sensitive to the roughness parameter; water level variations are less than 0.16 feet with a 25 percent of change in Manning's coefficients.
- The eddy viscosity is a parameter which defines turbulent transfer of momentum by eddies. Peclet number is used as the input parameter in this study instead of the traditional eddy viscosity method. The relationship between Peclet number and eddy viscosity is discussed in the previous section. With the Peclet number changing from 10 to 0.4 (25 times difference) in the channel, the maximum departure of water level is about 0.4 feet at the Railroad trestle and 0.8 feet at I-5 within the calibration time period. With the Peclet number changing from 0.1 to 1 (10 times difference) in the marsh area, the maximum departure of water level is about 0.16 feet at the Railroad Trestle and 0.3 feet at I-5 within the calibration period. The model is not significantly sensitive to Peclet number, but it could cause large distortion with inappropriate inputs, especially within regions that have significant velocity change.

The marsh porosity technique is used in conjunction with the traditional wetting and drying technique to enhance the model stability. The marsh porosity technique allows elements to transit gradually between wet and dry states. Several sets of marsh porosity parameters were tested, and results indicate that water levels are not sensitive to marsh porosity. However, velocities appear to be more sensitive to marsh porosity than water levels, especially at intertidal areas. However, sensitivity can be reduced with proper marsh porosity parameters.

4.3.3 Calibration Results

Model calibration was done for the same time period that the USACE used for their modeling of the site, the period from 3:00 AM on August 6 to 2:00 AM on August 7, 2002. Model predictions of tidal elevations were compared to measured tides at the railroad and I-5 bridges and are shown in Figure 4-13 and Figure 4-14. Tidal elevations simulated by the model correspond reasonably well with those measured both in terms of tidal phase (timing) and range (elevation). Calibration results at the I-5 Bridge are slightly better than that at the Railroad Bridge. The accuracy of calibration results are limited by the fact that tidal inlet bathymetry was not

measured on the same day the tidal elevations were measured. However, for purposes of comparing alternatives for this study, the model can reasonably replicate (predict) the existing tidal conditions in the wetlands as compared with measured values, and is therefore suitable for alternative simulations. A longer period of tidal calibration would be useful in evaluating possible systematic model error. A systematic error in the model could result in a trend of mean sea level either upward or downward over time. Due to the basic equations of continuity used for its calculations, this model has not shown this type of error in previous applications and is not anticipated to show it at San Elijo Lagoon. The relatively short calibration period is adequate to test the model's accuracy and can be relied on to show its suitability for predicting water levels over time at this site.

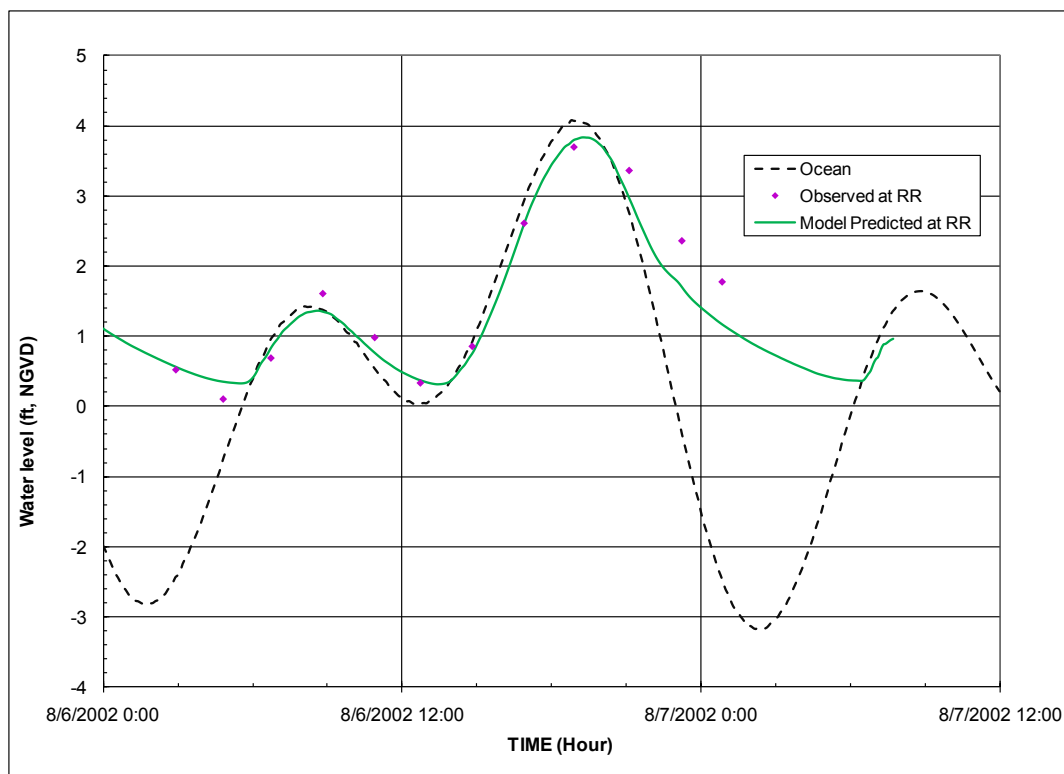


Figure 4-13: RMA2 Model Calibration Results at the Railroad Bridge

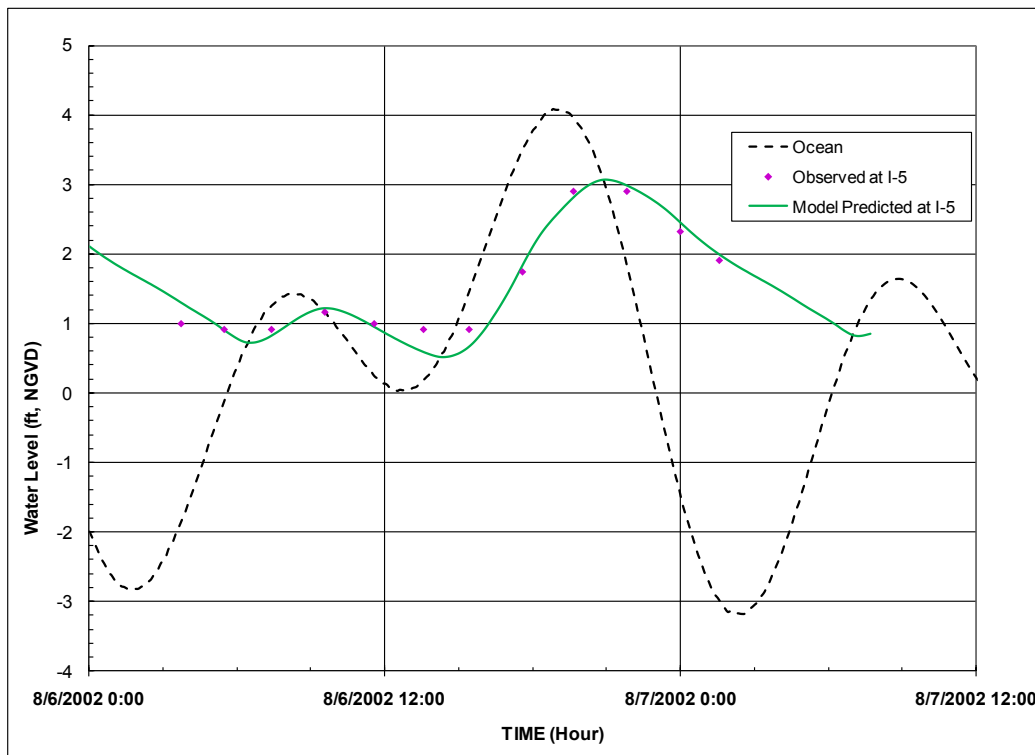


Figure 4-14: RMA2 Model Calibration Results at I-5 Bridge

4.3.4 Verification Results

Model verification was performed with numerical model parameters determined in the model calibration. The verification period was from January 1st to January 4th, 2008 corresponding to an event when relative water depths were measured in the lagoon. Water depths were measured as part of the development of TMDLs and were provided by the City of Encinitas. Water depths were collected in three locations: 1) the inlet, 2) Segment 2 (near the Nature Center), and 3) Segment 1 (immediate downstream of the I-5 Bridge) as shown in Figure 4-15. The measured water depths were converted into water levels by shifting them vertically to approximately match those predicted by the model. The timing of the readings was also shifted one hour to match the phasing of the ocean tide at the tidal inlet. It is possible that the time of depth measurements were based on daylight savings time which would offset the recorded time by one hour.

Model verification results are shown in Figure 4-16 through Figure 4-18. In general, both predicted tidal range in the lagoon matched well with the measured data, and phasing matched as well. The verification accuracy is limited by the lack of simultaneous bathymetry survey data available for the inlet and the I-5 bridge section, and by the water level data not being tied to a vertical datum. However, the model verification is considered adequate to demonstrate reasonable model predictions of tidal range, lags, and phasing for the purposes of preliminary engineering analyses and relative comparison of alternatives.



Figure 4-15: RMA2 Model Verification Gage Locations (Created in Google Earth)

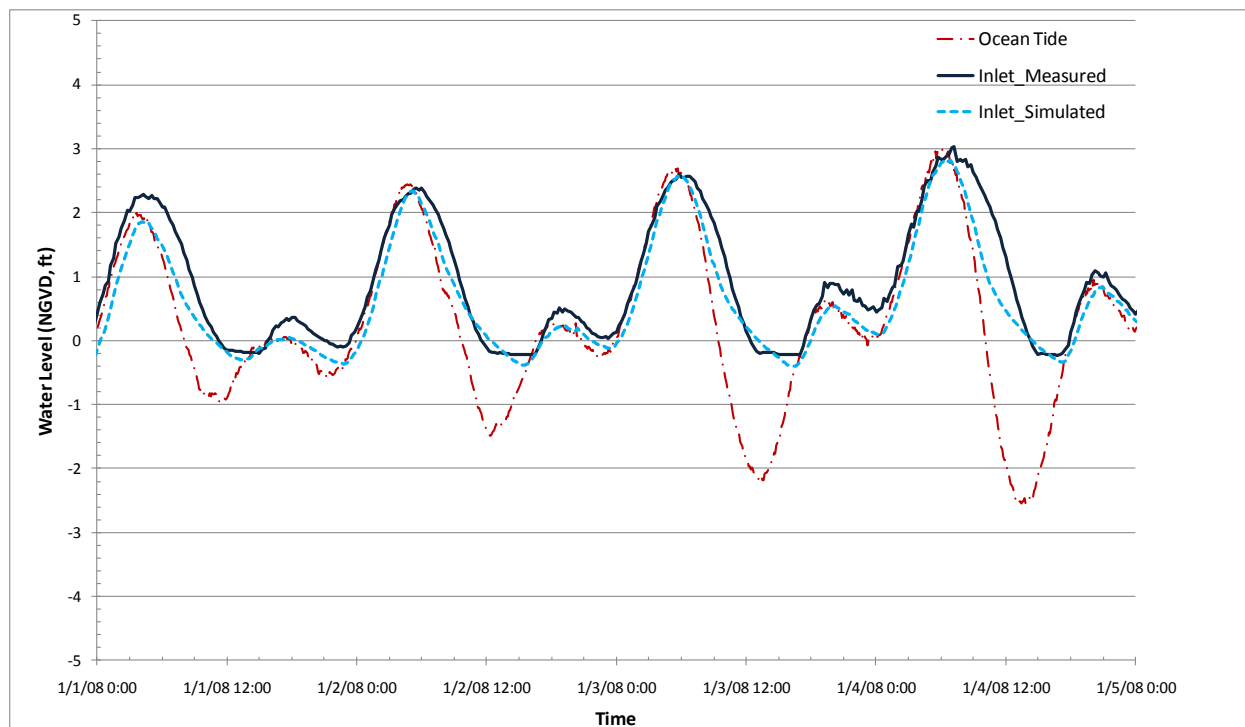


Figure 4-16: RMA2 Model Verification Results at the Tidal Inlet

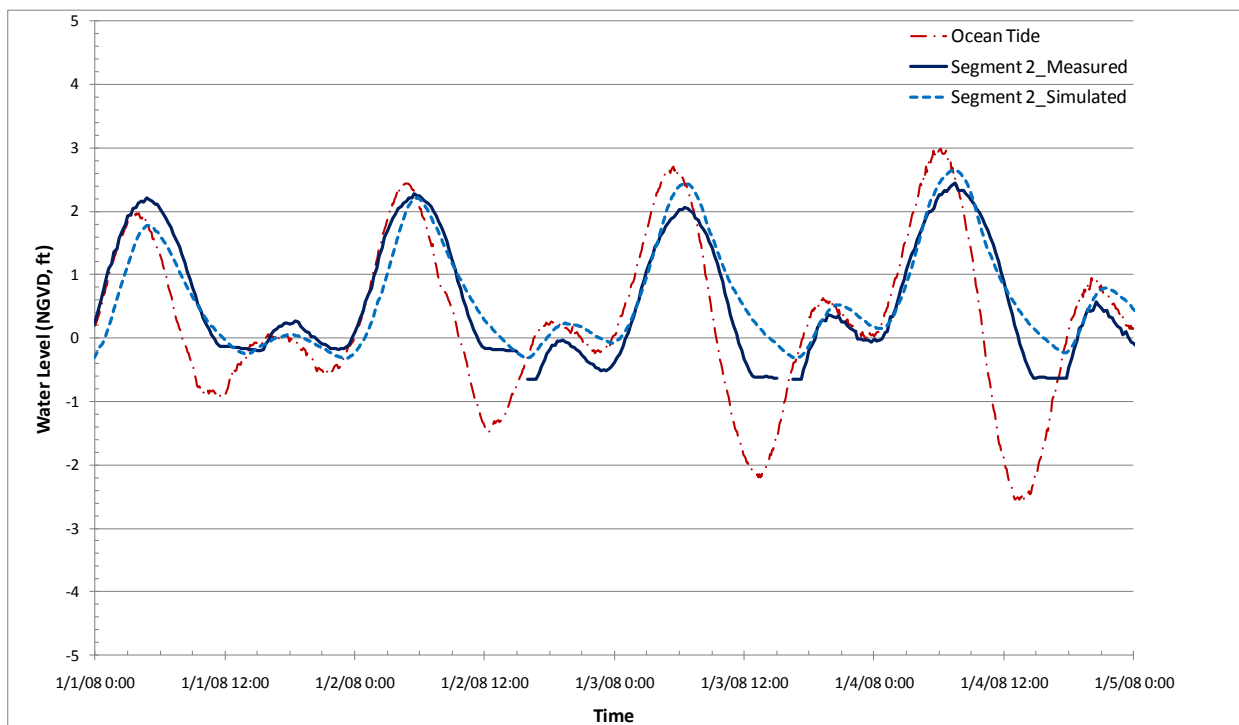


Figure 4-17: RMA2 Model Verification Results at Segment 2

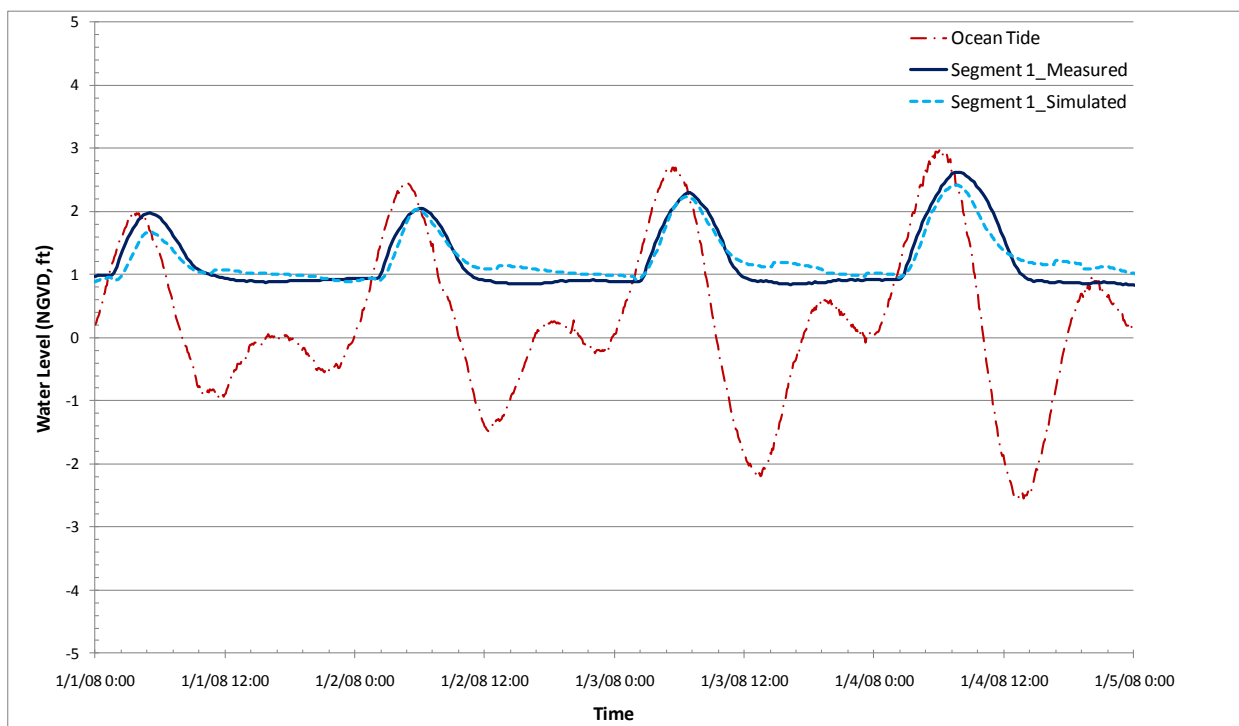


Figure 4-18: RMA2 Model Verification Results at Segment 1

4.4 Hydraulic Modeling Results

Modeling simulations were performed for tidal and flood flows for existing conditions and four proposed alternatives. The modeling parameters of the roughness coefficients and Peclet numbers calibrated for existing conditions were assigned for the alternative modeling. Results of the hydraulic modeling are discussed below.

Figure 4-19 shows virtual gage locations where hydraulic results are analyzed for existing conditions, Alternatives 1A, and 1B. Figure 4-20 shows virtual gage locations for Alternatives 2A and 2B. These locations are fixed for all modeling scenarios except they vary by alternative at the tidal inlet, depending on inlet location. To best present modeling results to inform the planning and design efforts, different sets of gages may be used for varying purposes, such as water level prediction, inundation frequency analyses, tidal velocity patterns, etc.

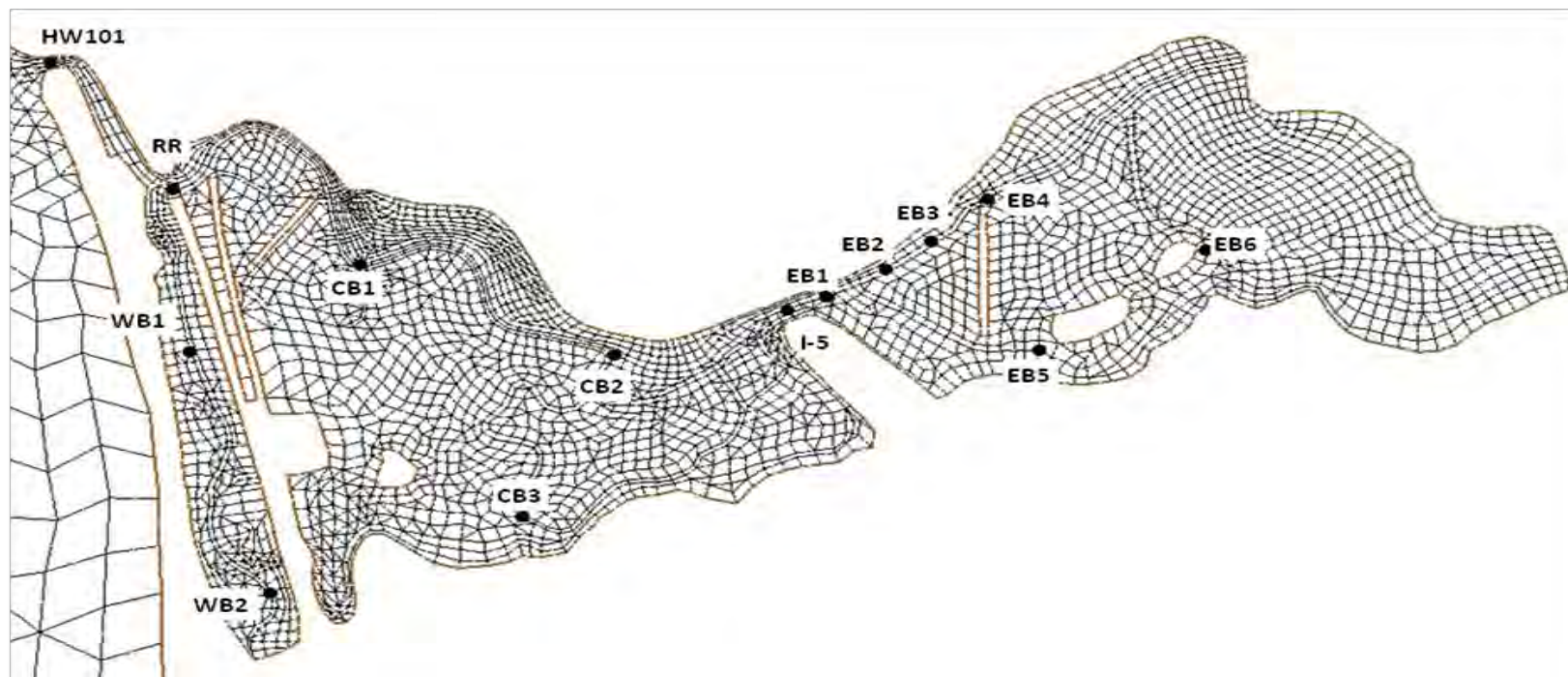


Figure 4-19: Virtual Gage Locations for Existing Conditions and Alternatives 1A and 1B

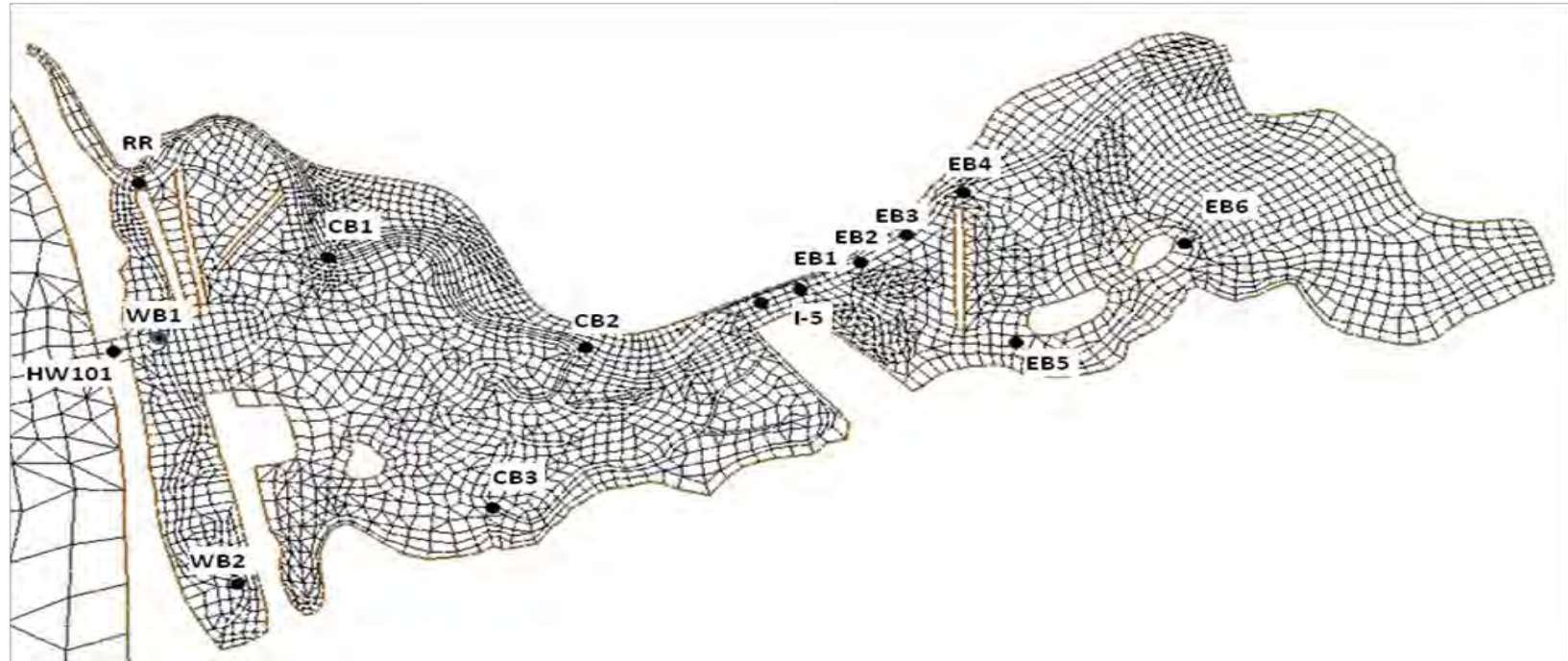


Figure 4-20: Virtual Gage Locations for Alternatives 2A and 2B

4.4.1 Flood Flow Hydraulics

4.4.1.1 Maximum Water Levels

The purpose of the flood hydraulic modeling is to determine the maximum water levels throughout the lagoon to a level of accuracy appropriate for planning purposes to quantify impacts of restoration on potential flooding. The hydrodynamic model runs were conducted for all alternatives under the 100-year flood combined with a highest measured high spring tide. For a specific location, the highest water level occurs when the highest measured high tide and the peak flood occur simultaneously. Results represent conditions of the tidal inlet and wetland basins immediately after construction is complete.

Sediment may accumulate in the lagoon over time, but will be flushed out from the main channel during stormflows prior to occurrence of the peak lagoon water level, so sufficient stormflow drainage will still occur to prevent flooding of adjacent areas. The flow velocity required for sand erosion is 3 feet per second (fps), and the flood will generate velocities of up to between 3 to 5 feet per second according to modeling. Modeling for Alternative 1B indicates that the stormflow velocity reaches 3 fps in the entrance channel approximately one hour prior to the water surface elevation peak in the central basin, so the shoal in the entrance channel will be cleared before the occurrence of the peak water surface elevation. Modeling presents velocities under the post-construction condition without any shoals. If shoals were in place, the stormflow velocity at the shoal will be even higher. Tidal flow monitoring in 2010 confirmed peak velocities of ebb tides at 5.5 fps. Sand bars should not impede the flood.

This process has been documented at nearby San Dieguito Lagoon where pre- and post-storm season measurements by Coastal Environments (2013) showed the erosion of the flood shoal in the entrance channel during a 13-year storm event in 1993. [Shoals at San Elijo Lagoon will be monitored and if discovered it will be removed during regular maintenance.](#)

Ideally, multiple model runs would be required to determine the absolutely highest water level throughout the lagoon with the greatest level of accuracy. However, this study is not a flood control design effort, but rather a component of wetland restoration analyses. Therefore, results can be slightly less detailed but still sufficiently accurate to render information suitable for planning and decision-making within the constrained schedule and budget. Modeling runs were performed for each alternative with the modeling tidal series shown in Figure 4-9 **Error! reference source not found.** as boundary input. Model runs was intended to maximize water levels in each basin and to maximize water levels at the tidal inlet. Results are summarized in Table 4-5 **Error! Reference source not found.**

The main roadway of concern is Manchester Avenue that extends along the entire northern boundary of the Lagoon. Other important features are the three bridges at Highway 101, the NCTD Railroad, and I-5. These features have been the focus of flood studies over time by Caltrans. Results indicate that for existing conditions and for Alternative 1A, a reach of

Manchester Avenue in the East Basin will be flooded during the combined event. However, the flood water level will be reduced by one half of a foot with proposed Alternative 1A. The table also shows the existing surface elevation of Manchester Avenue for comparison.

In contrast, the results also indicate that the maximum water level will be below Manchester Avenue for Alternatives 1B and 2A. Storm flood water levels are clearly reduced by the project upstream of I-5. Alternative 2B would provide similar flood water level reduction as Alternative 2A although it was not modeled as it was eliminated from consideration by the Lagoon Conservancy from being carried forward in environmental review. Alternatives 2A & 2B may not provide a 3 foot freeboard required by FEMA, but the future condition should be an improvement over existing flood conditions.

Table 4-5: Maximum 100-Year Flood Elevation (ft, NGVD) in the Wetlands in 2015 Based on +5.4-ft NGVD (Recorded Highest) Downstream Tidal Elevation

Virtual Gage Locations	Manchester Avenue Elevation	Existing	Alt 1A	Alt 1B	Alt 2A
HW101	N/A	5.3	5.3	5.3	5.3
RR	N/A	8.5	7.9	8.1	6.3
CB1	29.0	8.9	8.4	8.7	6.5
CB2	9.8	9.0	8.5	8.7	6.7
I-5	12.7	9.4	8.9	8.8	7.3
EB1	12.9	9.8	9.8	8.8	7.5
EB2	9.3	12.3	11.7	9.0	8.1
EB3	10.3	12.4	11.7	9.0	8.3
EB4	10.4	12.3	11.8	9.0	8.4
Note: Values in red indicate elevations above the roadway and represent flooding.					

4.4.2 Tidal Hydraulics and Hydrology for 2015

The purposes of the tidal hydraulic studies are to:

- Predict tidal elevations and flow velocities over time and space within the Lagoon, as compared to the open ocean (to serve as the basis for analyses of water quality and shoaling, and other related studies);
- Determine the tidal inundation frequency in the wetlands to determine probable habitat distribution; and
- Predict the statistics of tidal inlet hydraulics for the inlet design and stability analyses.

Tidal hydraulic modeling was done for both immediate post-construction conditions assumed to be in 2015, and for future 50-year conditions in 2065 estimated using a rate of sea level rise of 2 feet from 2015 (Moffatt & Nichol, 2010). The hydraulic modeling results in the wetland system and tidal inlet are discussed in the following sections.

4.4.2.1 Tidal Elevations

Hydraulic modeling results for each wetland alternative are analyzed for conditions representing immediate post-construction in 2015. Table 4-6 presents predicted tidal ranges, and the ocean tidal range for comparison. The tidal range difference between a wetland and the ocean represents the potential tidal muting in that specific location for that alternative. Table 4-7 presents the model-predicted spring high and low tide elevations. The table also provides additional information on muting and indicates whether the tidal muting occurs for high tides, low tides, or for both tidal conditions.

Table 4-6: Predicted Tidal Ranges for 2015

Alternative	Tidal Range (ft)					
	Ocean	HW101	WB1	CB2	I-5	EB4
Existing	7.97	4.56	3.99	3.85	3.78	3.76
1A	7.97	7.11	5.56	5.26	5.21	5.15
1B	7.97	6.58	5.44	5.42	5.42	5.43
2A	7.97	7.97	7.93	7.92	7.87	7.88
2B	7.97	7.97	7.88	7.88	7.88	7.88

Table 4-7: Predicted Spring High and Low Tidal Elevations for 2015

Alternative (1)	High and Low Tidal Elevations (ft, NGVD29)											
	Ocean		HW101		WB1		CB2		I-5		EB4	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Existing	4.38	-3.59	4.18	-0.38	3.65	-0.34	3.53	-0.32	3.51	-0.27	3.51	-0.25
1A	4.38	-3.59	4.35	-2.77	3.92	-1.64	3.76	-1.50	3.75	-1.46	3.75	-1.40
1B	4.38	-3.59	4.29	-2.29	3.88	-1.56	3.88	-1.54	3.88	-1.54	3.88	-1.54
2A	4.38	-3.59	4.38	-3.59	4.38	-3.56	4.37	-3.55	4.38	-3.49	4.39	-3.49
2B	4.38	-3.59	4.38	-3.59	4.38	-3.50	4.38	-3.50	4.38	-3.50	4.38	-3.50

Figure 4-21 through Figure 4-25 show the predicted tidal series in the wetlands and ocean for the existing and proposed alternative scenarios. The results are summarized below.

- For No Project (existing conditions), the inlet is narrow and long, and the inlet depth is limited by a bedrock and cobble sill at the mouth. Both high and low tides in the West Basin are muted by more than 1 foot compared to the ocean tides. The tides are further

muted in the Central and East Basins due to the constriction of the Railroad Bridge and narrow and meandering channels in the Central Basin.

- For Alternative 1A and Alternative 1B with the inlet at the existing location and inlet depth limited by the nearshore sill, the overall hydraulics are similar and controlled by the constriction at the mouth. Both high and low tides are muted, with low tides muted by more than 2 feet in the Central Basin. The narrow channel between Highway 101 Bridge and Railroad Bridge restricts flow to the Central Basin. The predicted tidal range in the East Basin is similar to that in the Central Basin, which indicates that the proposed channel cross-section under the I-5 Bridge is sufficient to not cause further muting in the East Basin. Both alternatives significantly reduce tidal muting and improve circulation in the wetland basins compared to existing conditions.
- For Alternatives 2A and 2B with the same proposed new tidal inlet location, the general wetland hydraulics are similar. There is no muting of the high tide, and muting of the low tide is very small. The low tide is muted approximately 0.1 feet in both the Central and East Basins. Hydraulically, these two alternatives reduce tidal muting and improve circulation in the wetland basins.

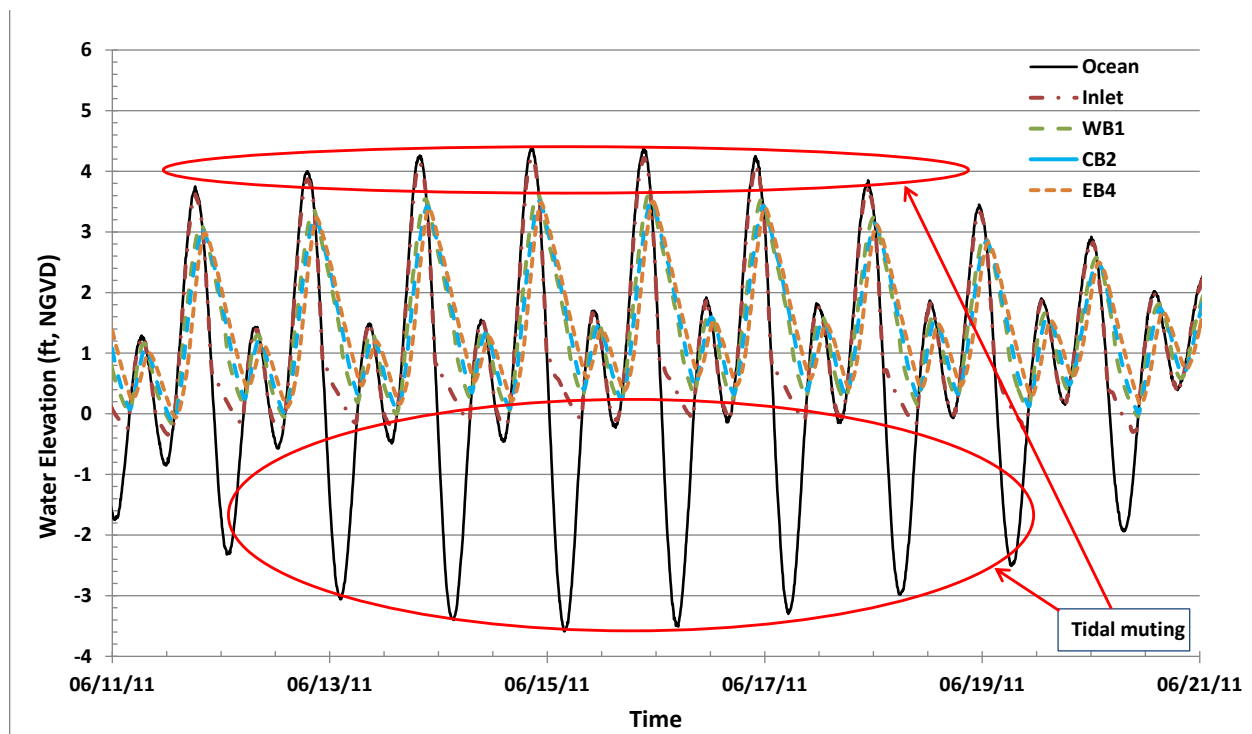


Figure 4-21: Predicted Tidal Elevations for No Project at 2015

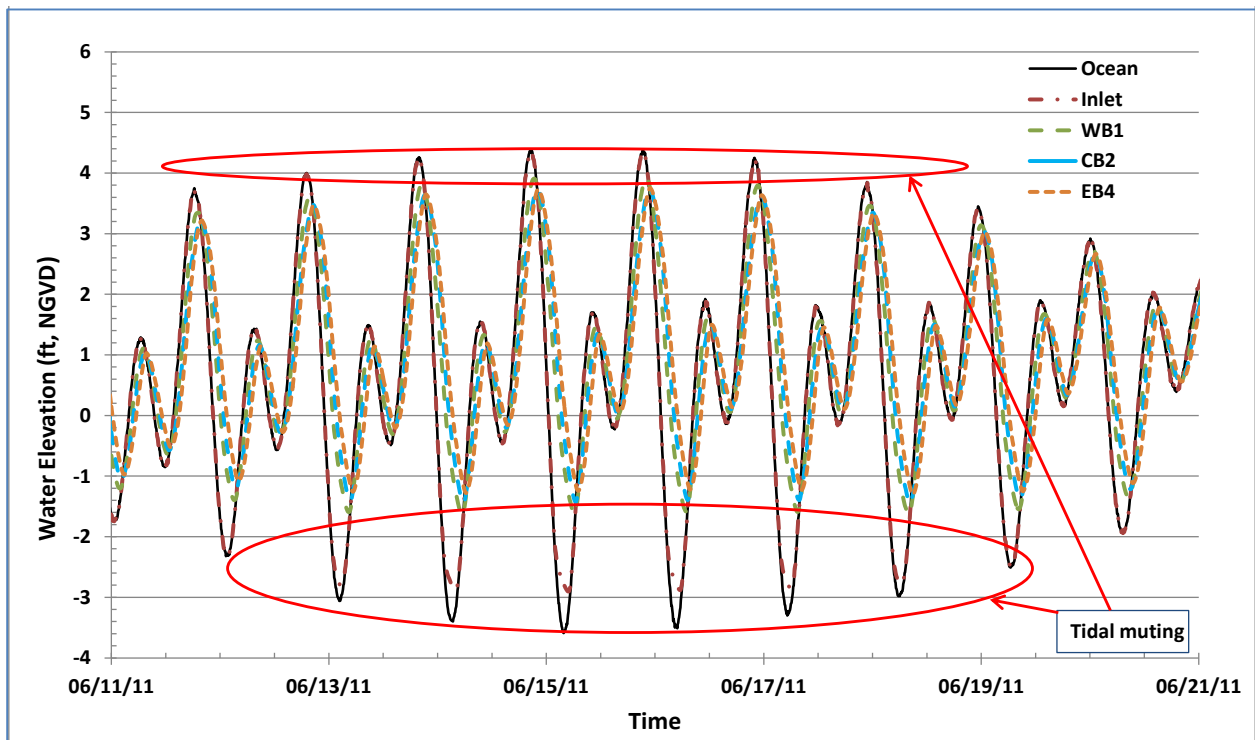


Figure 4-22: Predicted Tidal Elevations for Alternative 1A at 2015

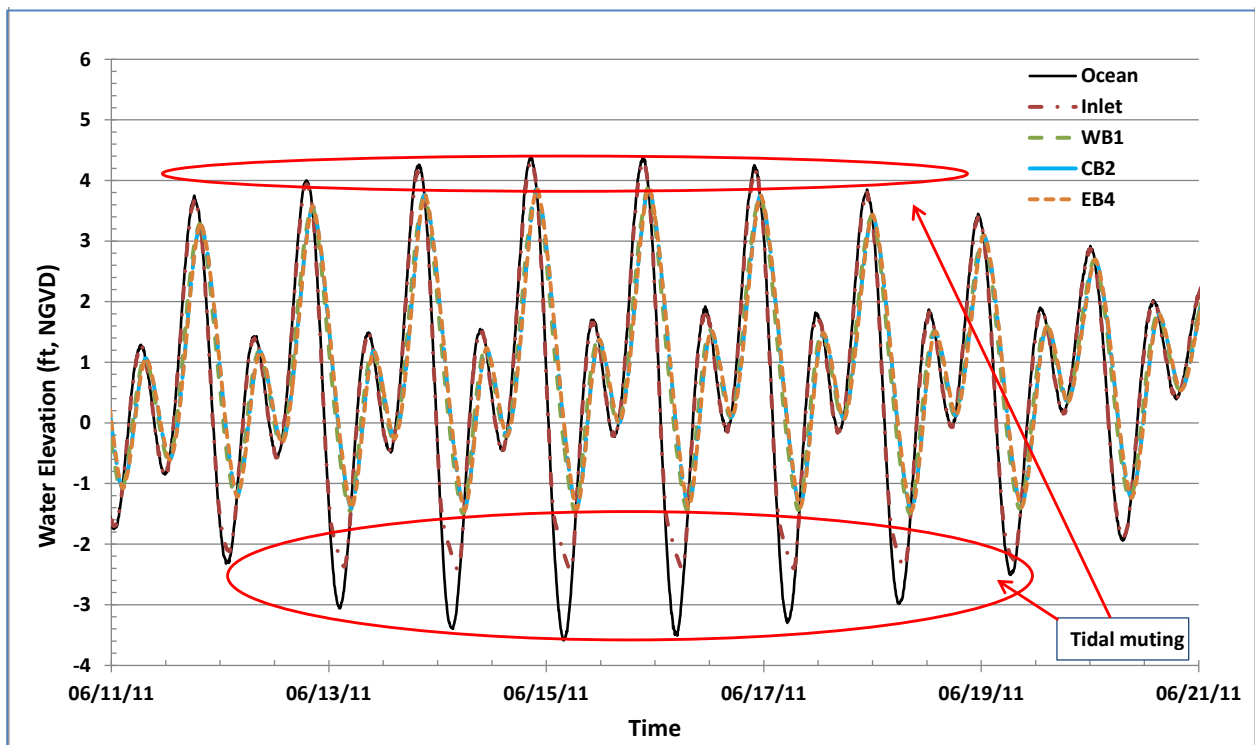


Figure 4-23: Predicted Tidal Elevations for Alternative 1B at 2015

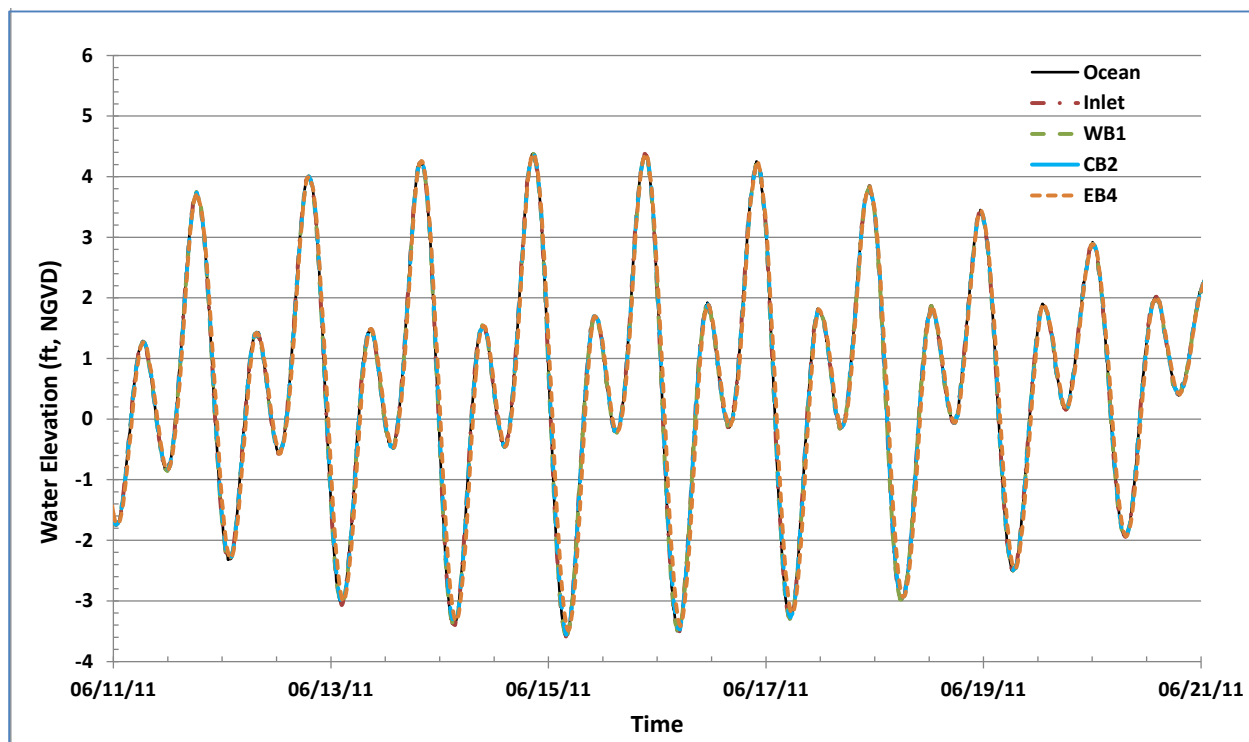


Figure 4-24: Predicted Tidal Elevations for Alternative 2A at 2015

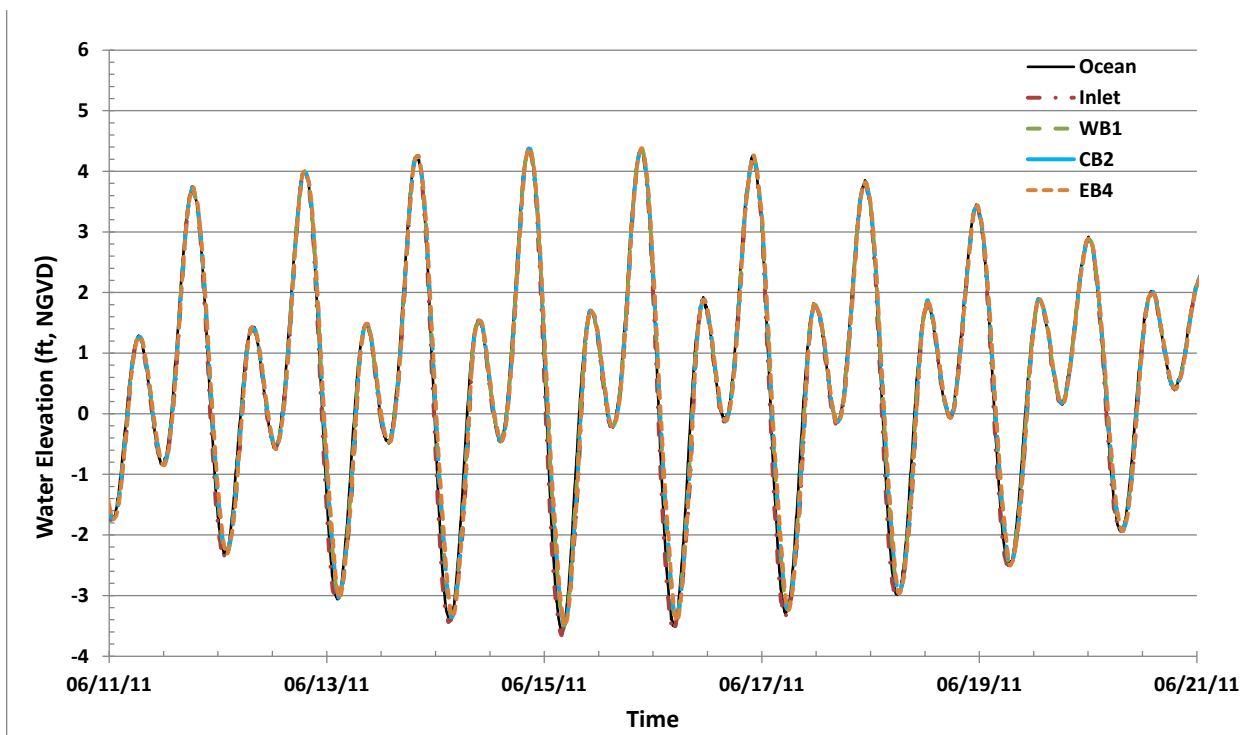


Figure 4-25: Predicted Tidal Elevations for Alternative 2B at 2015

4.4.2.2 Tidal Inundation Frequency

Tidal inundation frequency analyses were performed with tidal hydraulic modeling results. Inundation frequency is the percentage of time that the tidal elevation exceeds a certain elevation. It is an important factor for habitat design and distribution because the plants become established at particular inundation frequencies. Figure 4-26 through Figure 4-30 present predicted inundation frequencies for existing and four proposed wetland scenarios at 2015, or the post-construction condition. The following can be concluded from the tidal inundation frequency analyses:

- For No Project (existing conditions), both high and low tides are muted. Therefore, the vertical zonation (range of occurrence) of intertidal habitat is relatively narrow (compared to an un-muted, open-ocean condition) and is approximately 3 to 4 feet. Tidal inundation frequency in each basin is different due to effects of channel constriction caused by infrastructure, with a progressive decrease in the vertical range of possible intertidal habitat with distance to the east. A range of salt marsh habitats can occur on-site, but their areas will be constrained by the tidal range, and the habitat distribution on-site may be dominated by fewer species more suited to the tidal elevations.
- For Alternatives 1A and 1B, tides are still muted, but much less relative to existing conditions. Therefore, the vertical zonation of intertidal habitat is more extensive than for existing conditions. Elevations range 5.5 feet in the West Basin for both Alternatives. Elevations range 5.2 feet for Alternative 1A in the Central and East Basins and 5.4 feet for Alternative 1B in the same basins. A greater range of salt marsh habitat can occur on-site compared to existing conditions, but their areas will still be constrained by the tidal range. Any tidal muting could further constrain the elevations and distribution of salt marsh habitat. For Alternative 1B, creating a greater range of elevations on-site by grading/dredging would be appropriate to provide greater habitat diversity. Tidal muting from shoaling would constrain the tidal range and distribution of habitats, indicating maintenance dredging would be important in preserving habitat areas. Shoaling is addressed in a subsequent study. Shoaling does not bear on storm flood elevations in the Lagoon during significant flood events, however, as discussed previously.
- For Alternatives 2A and 2B, the inundation frequencies in the wetland basins closely mimic that in the ocean, and the vertical zonation of intertidal habitats is maximized at 7.9 feet in the entire Lagoon. This situation indicates that the tidal inlet design is sufficient in cross-sectional area and bed elevation to approximately convey full tidal circulation in all wetland basins. As a result, the full range of salt marsh habitats should occur on-site. Similar to Alternative 1B, creating a greater range of elevations on-site by grading/dredging would be appropriate to provide greater habitat diversity. As with previous alternatives, any tidal muting from shoaling (addressed in a subsequent study) would constrain the tidal range and distribution of habitats, thus maintenance dredging would be important in preserving habitat areas. Shoaling does not bear on storm flood

elevations in the Lagoon during significant flood events, however, as discussed previously.

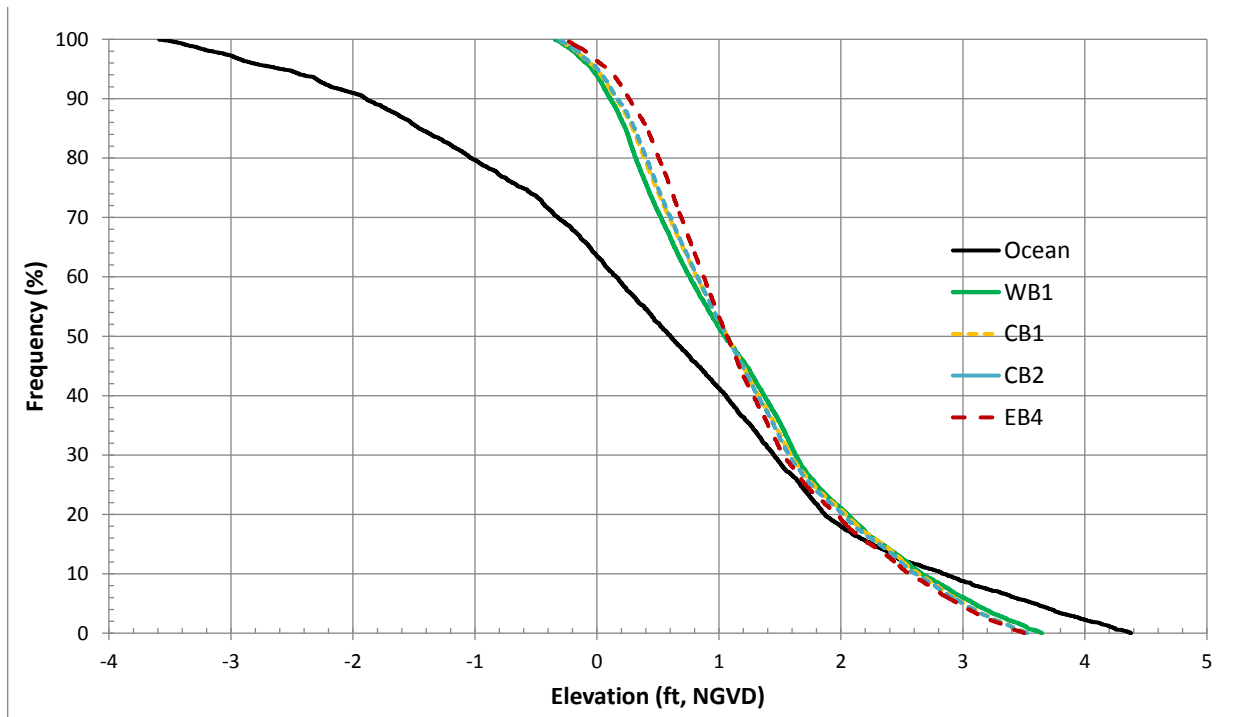


Figure 4-26: Inundation Frequency of No Project at 2015

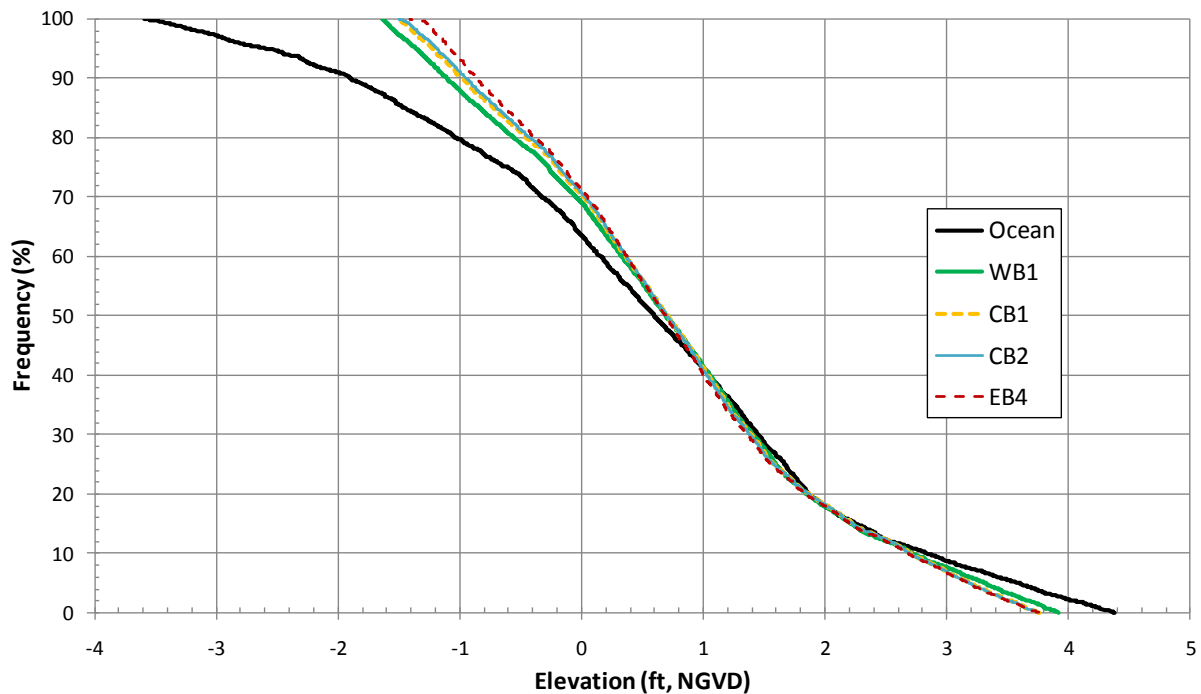


Figure 4-27: Inundation Frequency for Alternative 1A at 2015

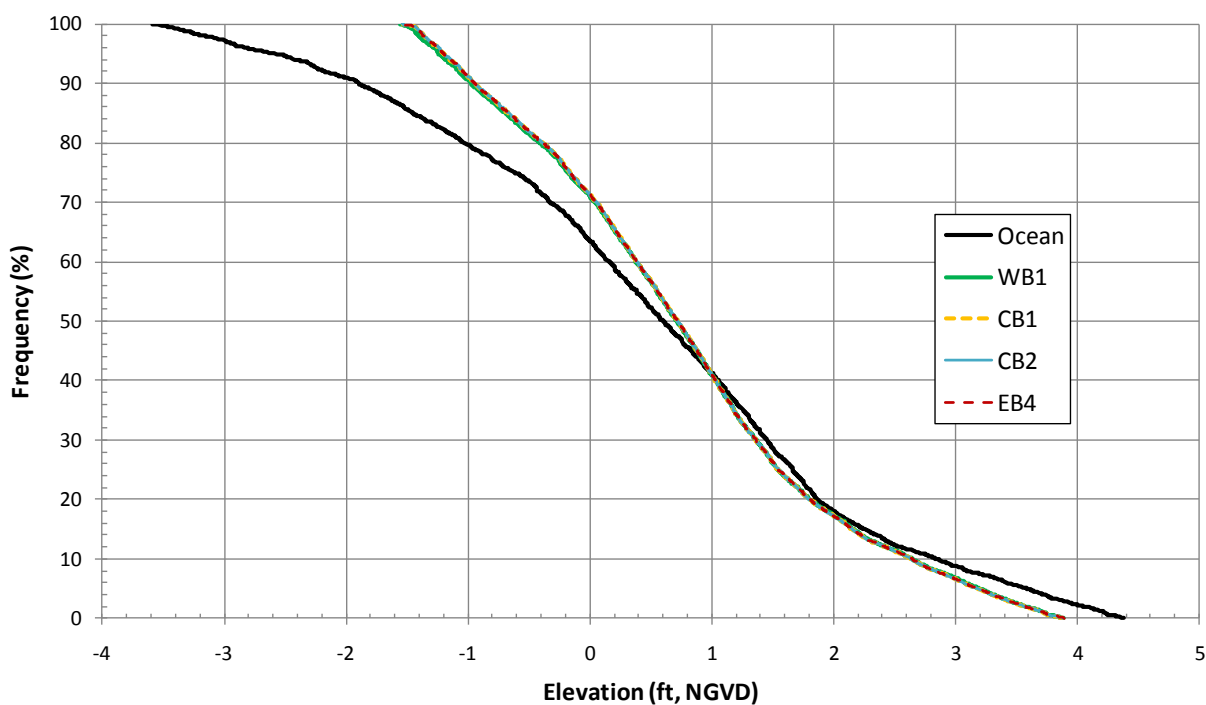


Figure 4-28: Inundation Frequency for Alternative 1B at 2015

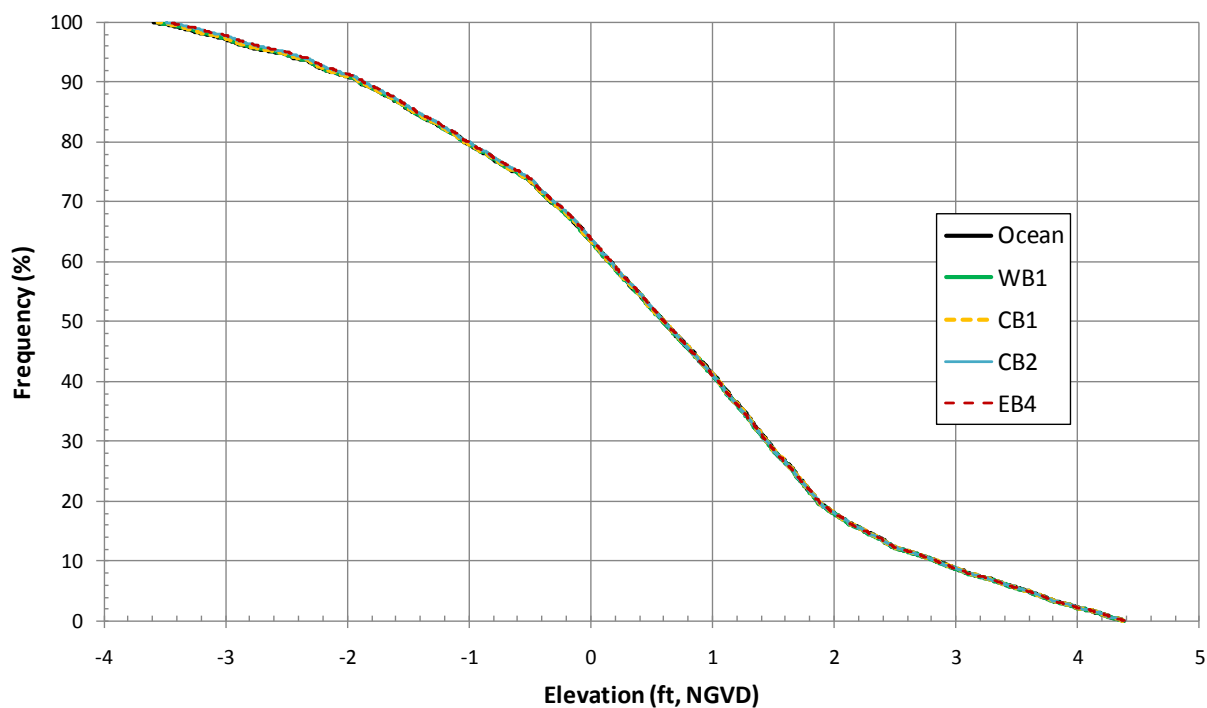


Figure 4-29: Inundation Frequency for Alternative 2A at 2015

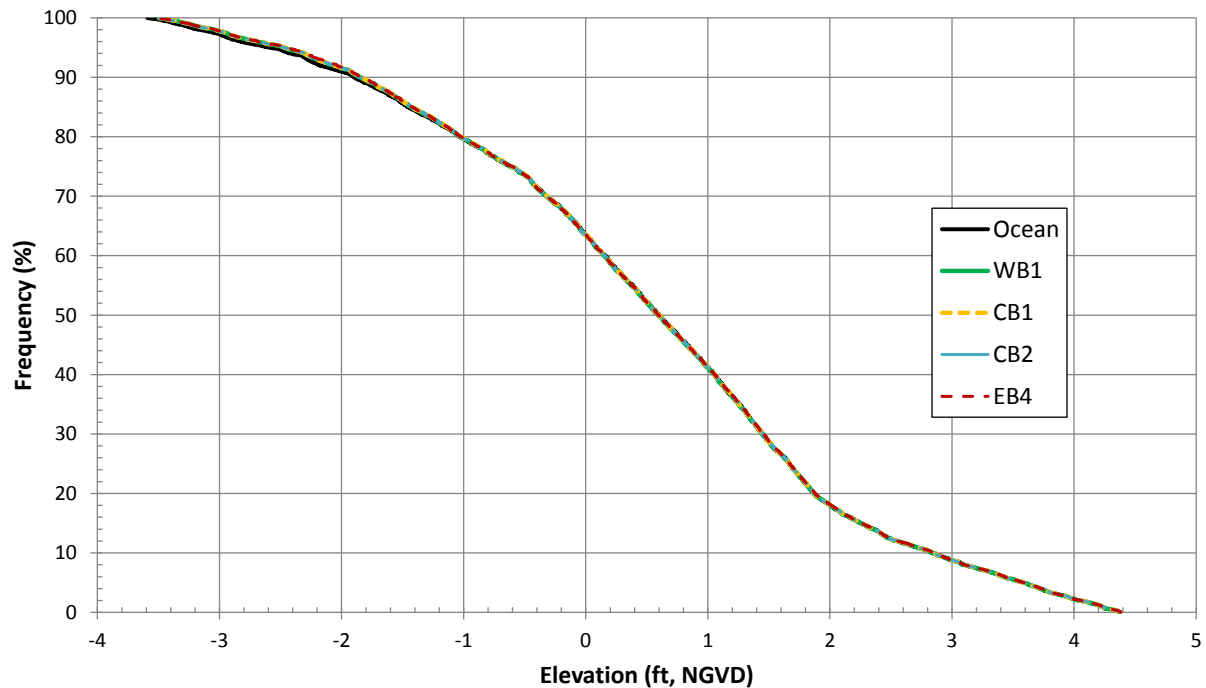


Figure 4-30: Inundation Frequency for Alternative 2B at 2015

4.4.2.3 Tidal Hydraulics at the Tidal Inlet

Tidal flow velocities vary within the wetlands and peak at the inlet. The magnitude and duration of tidal flow velocities at the inlet are important to inlet stability. The depth-averaged tidal velocities at the center of the inlet for the No Project (existing conditions) and for the alternatives are summarized in Table 4-10. The duration of outgoing (ebbing) tides is also important to inlet stability. Columns (5) and (6) give the percentage of time of tidal ebbing and flooding at the inlet. The ratio of the duration of the tidal ebb to the tidal flood shown in column (7) is equal to the ebb values in column (5) divided by the flood values in column (6). The larger the ratio, the longer the ebb duration and the greater the probability of inlet stability. For Alternative 1A (with a deeper inlet to -4 feet NGVD), the duration ratio of 1.48 means the total duration of tidal ebbing is 48 percent longer than that of tidal flooding. Figure 4-31 illustrates tidal inlet velocities and tidal elevations for Alternative 1A.

Both the tidal flow velocity and the tidal series at the inlet are not symmetrical. The general water depth in the inlet is greater during tidal flooding periods than that during tidal ebbing periods (shaded in yellow) in Figure 4-31. Therefore, it requires more time for the basin to drain during ebbing than to fill by the ocean during flooding because of the shallow inlet depth. Also, the ebb tidal flow velocity is higher than the flood tidal flow velocity. A minimum tidal flow velocity of 3 feet per second (fps) is typically required to suspend and erode sand to help maintain a stable inlet (scour velocities). The duration of ebb and flood velocities higher than 3 fps is given in Columns (8) and (9). The values in these columns are the percentage of time

velocities exceed 3 fps during the particular flow direction. For example in existing conditions, the value 14 (8) is the percent of time of the ebbing velocities exceed 3 fps at the inlet.

Tidal inlet flow velocity is one of many indicators determining inlet stability. The maximum ebb tidal velocity is greater than the flood tidal velocity for all scenarios (the existing condition, and all alternatives), which is the minimum requirement for a self-scouring inlet. However, as the existing inlet is not stable due to various factors, the data need closer scrutiny in the inlet stability study. Also, the peak ebb tidal velocity at the inlet is higher than the peak flood tidal velocity for each scenario, indicating that the inlet is ebb-dominant for all scenarios at 2015. Variations in wave climate (direction, frequency, height, and period) and sediment supply are equally important in evaluating inlet stability and will be considered in a subsequent inlet stability study.

Table 4-8: Summary of Tidal Inlet Hydraulic Results at 2015

Alternative (1)	Year (2)	Maximum Velocity at Inlet (fps)		Overall Duration at the Inlet (% of Time)		Ratio of Overall Duration of Ebb versus Flood at Inlet (%) (7)	Duration of Velocity over 3 fps at Inlet (%)	
		Ebb (3)	Flood (4)	Ebbing (5)	Flooding (6)		Ebbing (8)	Flooding (9)
Existing	2015	5.1	3.2	60	40	1.48	14	1.0
1A	2015	5.2	1.8	52	48	1.10	9.5	0.0
1B	2015	6.9	2.1	52	48	1.09	8.3	0.0
2A	2015	3.0	2.6	51	49	1.03	0.1	0.0
2B	2015	7.2	6.7	50	50	1.00	16	18

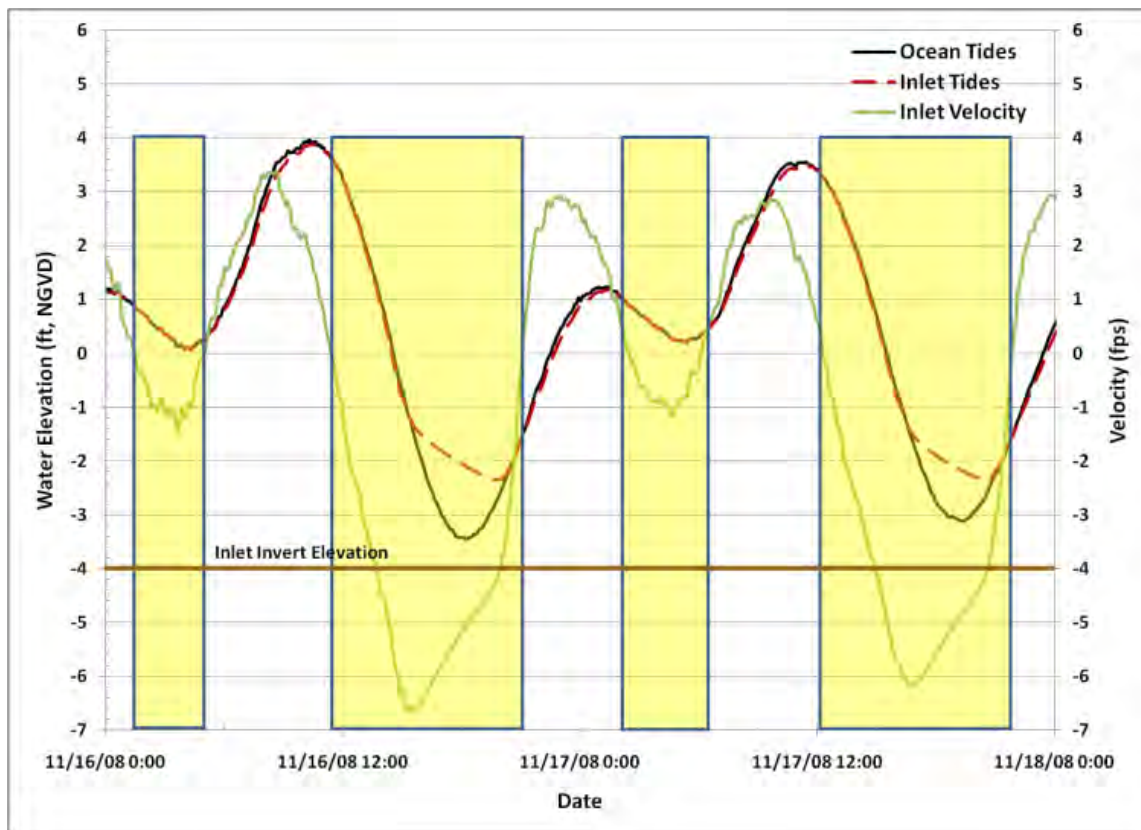


Figure 4-31: Alternative 1A Tidal Inlet Velocity and Tidal Elevations at 2015

Note: Yellow boxes represent periods of tidal ebbing.

4.4.3 Tidal Hydraulics in the Year 2065 with Sea Level Rise

4.4.3.1 Tidal Elevations

A sea level rise report was prepared as part of this project (Moffatt & Nichol, 2010). The report roughly estimated that the sea level would rise approximately 2.0 feet by the mid-term planning horizon of 2065, or 50 years after construction assumed for 2015. Therefore, a 2-foot sea level rise is added to the tidal series discussed in Section 4.2.4.2 to represent the new future tidal series for 2065. Although certain data suggest an expansion in the ocean tidal range over time with sea level rise, for purposes of this study it is assumed that the ocean tidal range would remain the same as existing over time, and wetland basins will be in the post-construction condition. Estimation of an increase in the future tidal range is too conjectural to apply to this study with any confidence.

Modeling is based on the assumption that Lagoon conditions in 2065 are maintained in the as-built construction condition of 2015, which is highly unlikely and this renders the results as the absolute best possible case that could ever occur. Much more likely is that some measure of shoaling will have occurred by 2065, even if diligent maintenance of the Lagoon shoals occurs,

along with episodic scour during significant storm flood events. Therefore the results for tide conditions presented herein are likely to be more promising than should be expected, and should only be used for relative comparisons between alternatives rather than absolute predictions of future water level conditions. A study on shoaling and tidal muting was completed that better clarifies future conditions (M&N 2011). Shoaling does not bear on storm flood elevations in the Lagoon during significant flood events, however, as discussed previously.

Virtual gage locations for extracting modeling results for the No Project and four alternative scenarios are shown in Figure 4-19 and Figure 4-20. Figure 4-32 through Figure 4-36 present the predicted tidal series in wetland basins in 2065. Table 4-9 summarizes tidal ranges under the future tidal condition. Hydraulic results at the start of the planning horizon in 2015 are also included in the table for comparison. The ocean tidal range is also included in the table.

Results show that tidal muting in wetland basins consistently decreases as sea level rises. This is to be expected because raising the water level produces a similar effect to deepening and widening the inlet. While the model shows this as a result, the actual magnitude of this effect in the future is uncertain because shoaling may occur to partially offset these effects to tides. This reduced muting effect over time has not been recorded at either Batiquitos Lagoon for the 10-year post-construction monitoring period, or the 2-year post-construction period at Bolsa Chica (Merkel & Associates, 2007 and 2009). In fact, the opposite condition has occurred at both sites as shoaling has compressed the tidal range since construction, as was predicted. The reduction of muting varies from alternative to alternative, and from location to location. Alternative 1B shows the most significant reduction in muting in 2065 as compared to 2015. Alternative 1A has the second largest reduction in tidal muting for the same period. No Project (existing conditions) may also have a larger tidal range in 2065 than in 2015. The tidal range differences are very small for Alternatives 2A and 2B since the basins under these two alternatives will already experience nearly full tidal range in 2015. Table 4-10 presents the predicted future spring high and low tides. This table provides additional information on muting and indicates whether the tidal muting is for high tides, low tides, or both. Both high and low tides will still be muted under existing conditions, and for Alternatives 1A and 1B. Alternatives 2A and 2B could potentially experience conditions closer to full ocean tides in 2065 if shoaling does not pose a restriction. Shoaling does not bear on storm flood elevations in the Lagoon during significant flood events, however, as discussed previously.

This analysis for year 2065 indicates that without shoaling, hydraulics for Alternatives 1A and 1B will become more similar to those of Alternatives 2A and 2B over time. Shoaling may occur and could affect tidal hydraulics (although not storm flooding), so this result should be considered in this context. The difference in tidal hydrology between alternatives with the existing tidal inlet location and those with a new tidal inlet location may progressively decline if sea level rise outpaces any shoaling. Tidal hydraulic and hydrologic conditions for the alternatives with the existing inlet location do not yet become equal to those with a new inlet by 2065, even without any shoaling. However, it is possible that if sea level rises by the amount predicted by some researchers (e.g., 5.5 feet) and this rate outpaces the rate of any shoaling, then alternatives with the existing inlet may experience more similar tidal conditions as those with a new inlet.

Table 4-9: Summary of Modeling Tidal Range at 2015 and 2065 Without Shoaling

Alternative Year	Ocean	HW101		WB1		CB2		I-5		EB4	
		2015	2065	2015	2065	2015	2065	2015	2065	2015	2065
Existing	7.97	4.56	5.41	3.99	4.41	3.85	4.19	3.78	4.01	3.76	3.97
1A	7.97	7.11	7.67	5.56	5.99	5.26	5.56	5.21	6.31	5.15	5.39
1B	7.97	6.58	7.39	5.44	5.74	5.42	5.70	5.42	5.71	5.43	5.72
2A	7.97	7.97	7.96	7.93	7.96	7.92	7.94	7.87	7.94	7.88	7.95
2B	7.97	7.97	7.97	7.88	7.93	7.88	7.95	7.88	7.95	7.88	7.96

Table 4-10: Summary of Spring High and Low Tides at 2065 Without Shoaling

Alternative (1)	High and Low Tidal Elevations (ft, NGVD29)											
	Ocean		HW101		WB1		CB2		I-5		EB4	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Existing	6.38	-1.59	6.05	0.64	5.40	0.99	5.34	1.15	5.28	1.27	5.25	1.27
1A	6.38	-1.59	6.31	-1.36	5.83	-0.16	5.72	0.17	5.70	0.24	5.69	0.30
1B	6.38	-1.59	6.27	-1.12	5.89	0.15	5.89	0.19	5.90	0.18	5.90	0.18
2A	6.38	-1.59	6.37	-1.59	6.37	-1.59	6.38	-1.56	6.38	-1.56	6.39	-1.56
2B	6.38	-1.59	6.37	-1.59	6.37	-1.56	6.38	-1.57	6.38	-1.57	6.38	-1.58

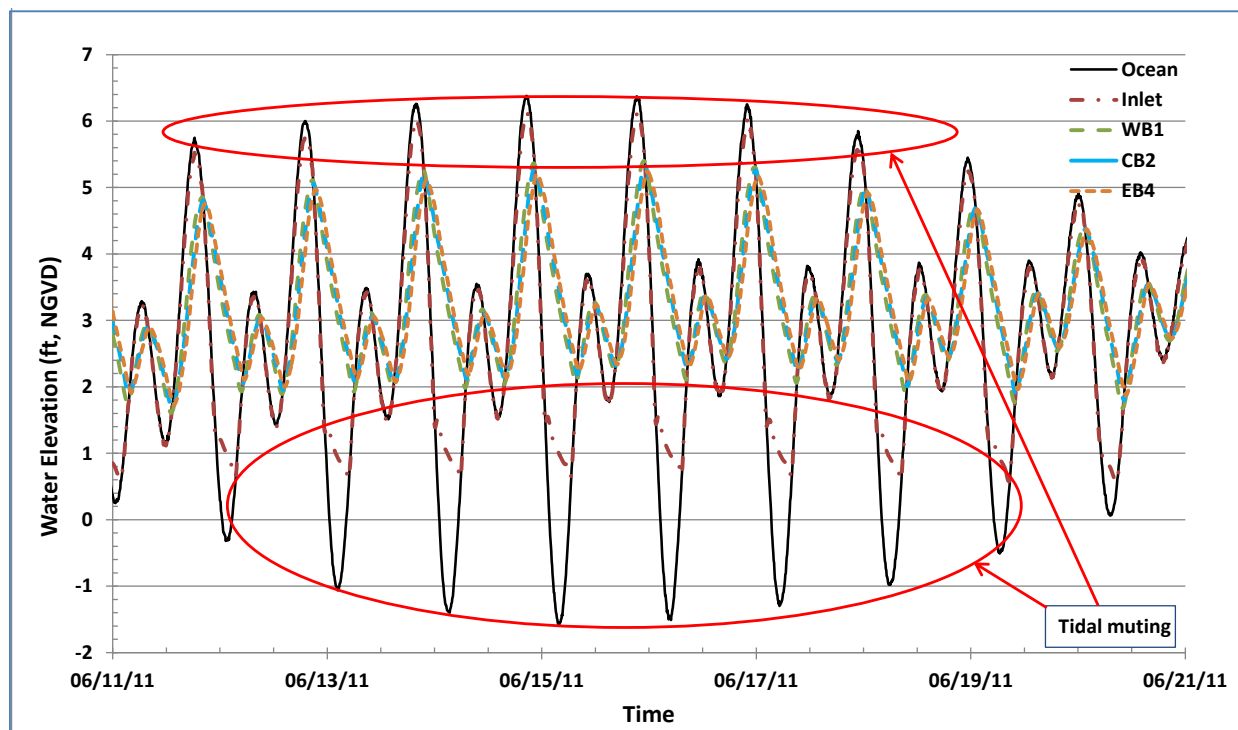


Figure 4-32: Predicted Tidal Elevations for No Project at 2065 Without Shoaling

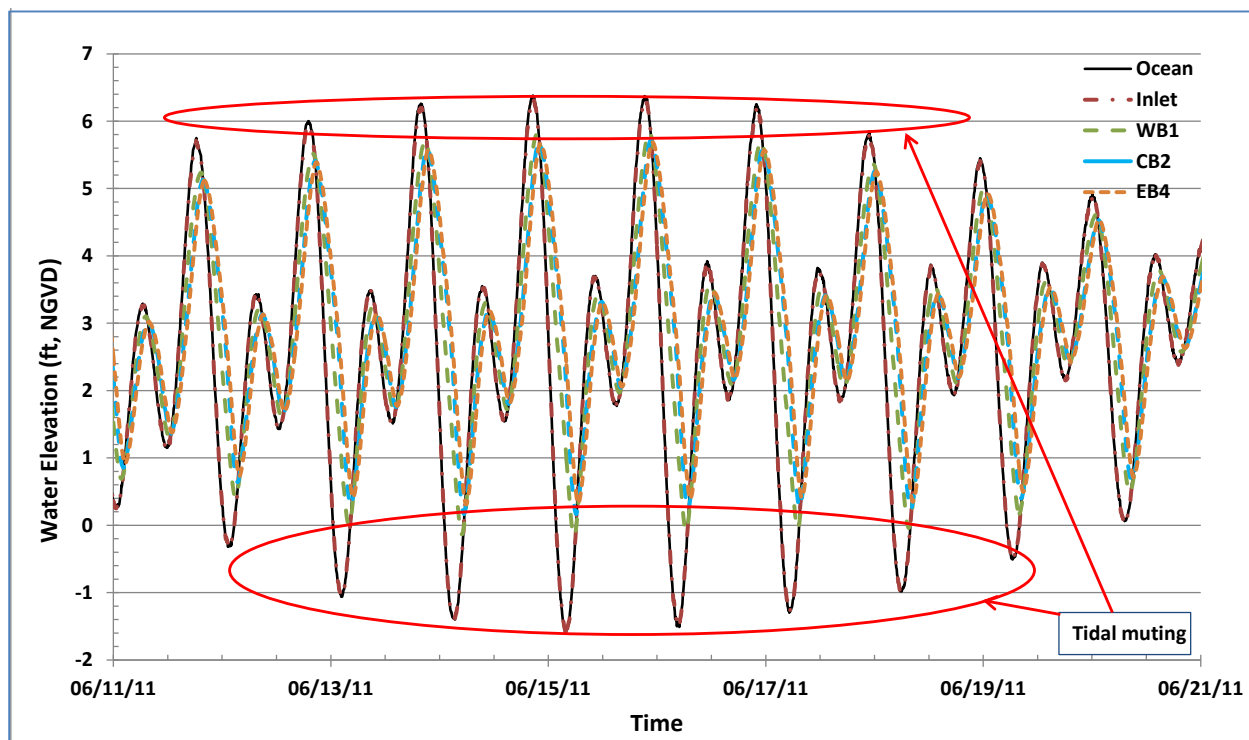


Figure 4-33: Predicted Tidal Elevations for Alternative 1A at 2065 Without Shoaling

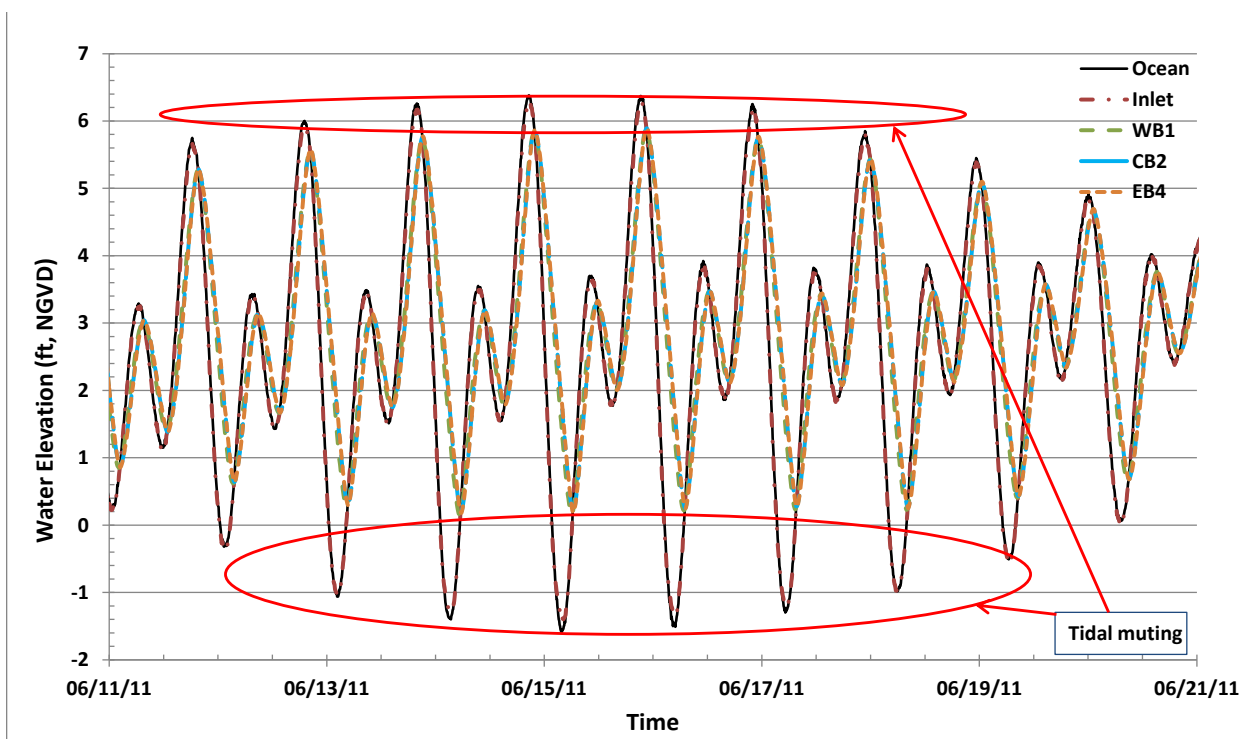


Figure 4-34: Predicted Tidal Elevations for Alternative 1B at 2065 Without Shoaling

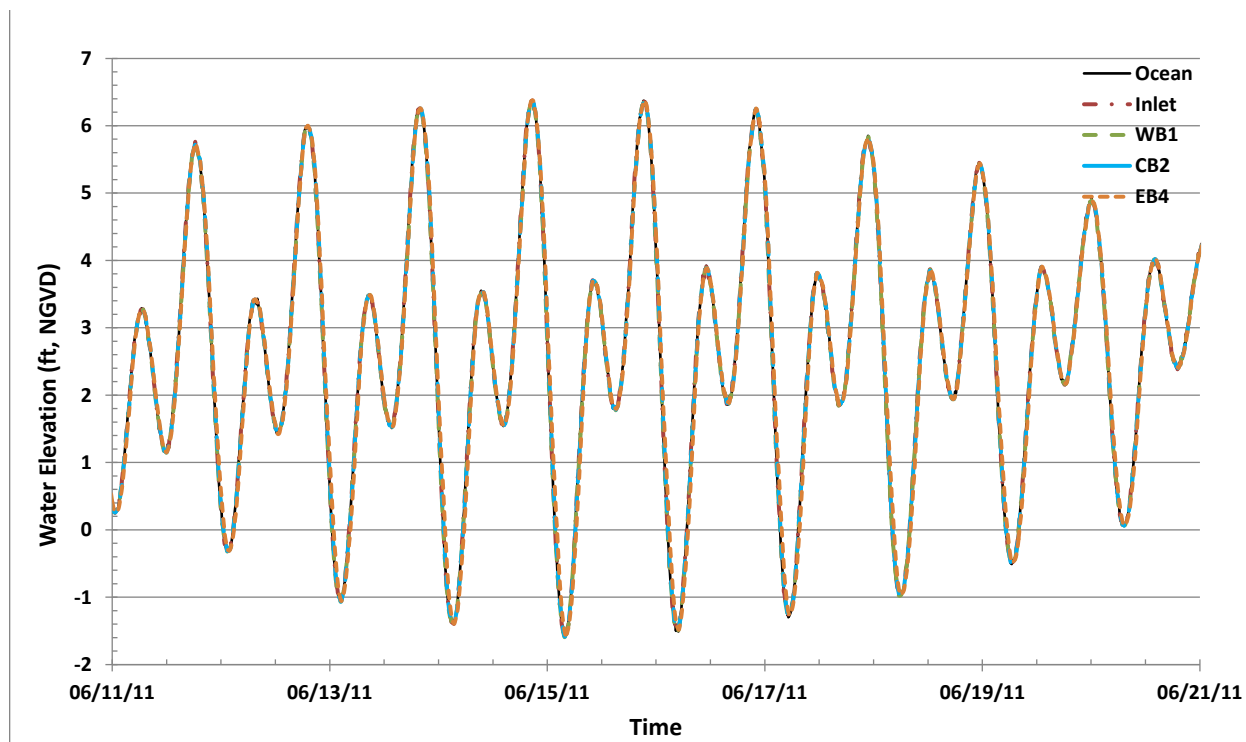


Figure 4-35: Predicted Tidal Elevations for Alternative 2A at 2065 Without Shoaling

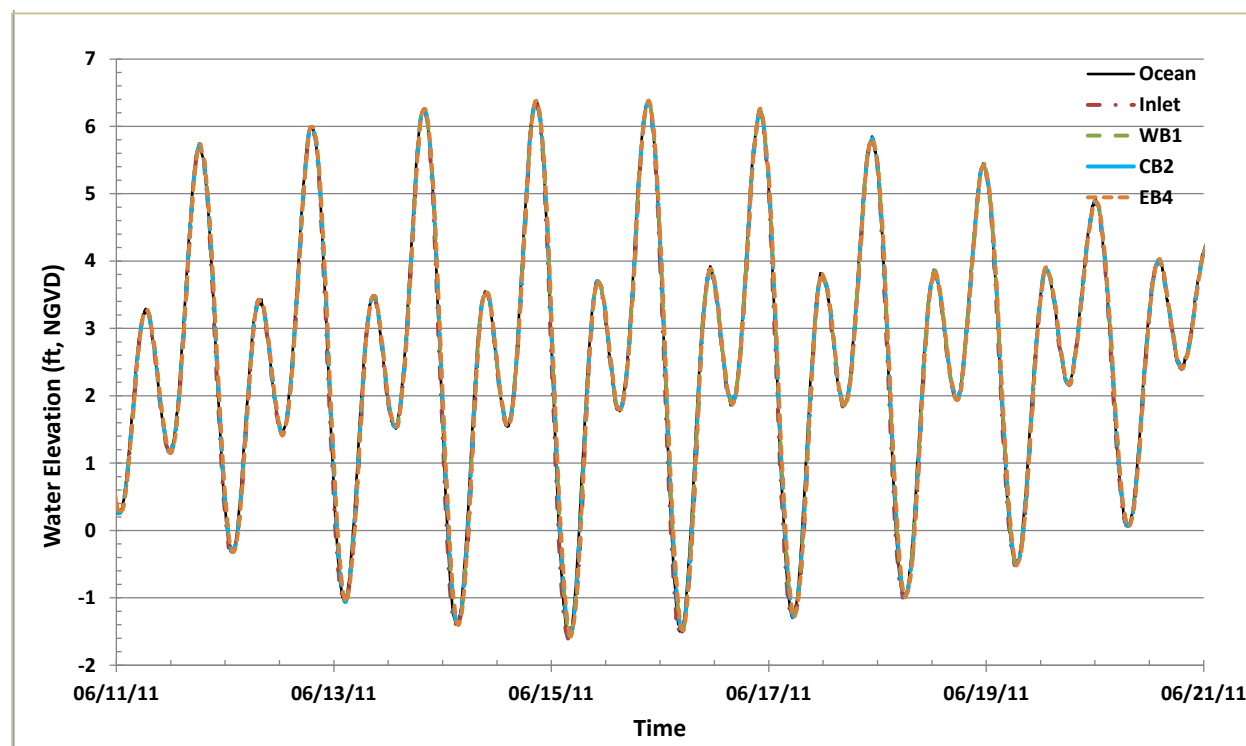


Figure 4-36: Predicted Tidal Elevations for Alternative 2B at 2065 Without Shoaling

4.4.3.2 Tidal Inundation Frequency

Figure 4-26 through Figure 4-30 present predicted tidal inundation frequency curves for No Project (existing conditions) and the four proposed scenarios in 2065. As is discussed above, modeling is based on the assumption that Lagoon conditions in 2065 are maintained in the as-built construction condition of 2015. Results presented herein should be used for relative comparisons between alternatives rather than absolute predictions of future water level conditions. The following can be concluded, with caution, from the tidal series and inundation frequency curve analyses:

- For No Project (existing conditions), both high and low tides would still be muted even with a 2-foot of sea level rise, however, to a less extent than for 2015 if no shoaling occurs. Conditions in 2015 show a vertical zonation of intertidal habitat of approximately 3 to 4 feet. By 2065, the vertical zonation of the intertidal habitat band increases by 0.4 feet in the West Basin, 0.3 feet in the Central Basin, and 0.2 feet in the East Basin with no shoaling. However, the vertical zonation (range of occurrence) of intertidal habitat is still relatively narrow compared to an un-muted, open-ocean condition). As with conditions in 2015, tidal inundation frequency in each basin varies due to effects of channel constriction caused by infrastructure, with a progressive decrease in the vertical range of possible intertidal habitat with distance to the east. A range of salt marsh habitats can occur on-site, but their areas will be constrained by the tidal range, and the habitat distribution on-site may be dominated by particular species more suited to the tidal elevations. These results indicate that for future conditions the inlet channel between HW101 and the Railroad bridge is too narrow to provide full tidal circulation, even with a 2-foot depth increase in the tidal inlet from sea level rise, assuming no shoaling. The tide range still decreases from the West Basin to the Central Basin and from the Central Basin to the East Basin, indicating that narrow and meandering channels in the Central Basin and I-5 Bridge will still restrict tidal circulation.
- For Alternative 1A with no changes proposed to existing infrastructure and no shoaling, both high and low tides are still muted, but to a lesser extent than they are in 2015. In 2015, the vertical zonation ranges from approximately 5.6 feet in the West Basin, to 5.3 feet in the Central Basin and 5.2 feet in the East Basin. By 2065, the intertidal habitat band increases by 0.4 foot in West Basin, 0.3 foot in Central basin and 0.2 foot in East Basin if shoaling does not occur. A greater range of salt marsh habitat can occur on-site in 2065 compared to existing conditions, and their areas will expand compared to conditions in 2015, but will still be somewhat constrained by the tidal range. Any tidal muting from shoaling would further constrain the elevations and distribution of salt marsh habitat, but may be offset by sea level rise.
- For Alternative 1B with proposed dredging of the tidal inlet and channel under the Railroad and the widening of I-5 channel, both high and low tides will still be muted, but to a lesser extent than in 2015 assuming no shoaling. Tidal muting in West Basin is reduced by 0.3 feet from 2015 to 2065, and the intertidal habitat band increases vertically from 5.4 feet to 5.7 feet if no shoaling occurs. A progressively larger range of

salt marsh habitat can occur on-site for Alternative 1B compared to Alternative 1A, with a more modest constraint imposed by the tidal range. Shoaling near the inlet mouth could further constrain tidal range and should be addressed. Creating a greater range of elevations on-site by grading/dredging would be appropriate to provide greater habitat diversity. Proposed channel widening under the I-5 Bridge will eliminate tidal muting between the Central Basin and the East Basin.

- For Alternatives 2A and 2B, the inundation frequencies in the wetland basins closely mimic that in the ocean in 2065 as they also do in 2015, and the vertical zonation of intertidal habitats is maximized at approximately 8.0 feet in all basins if no shoaling occurs. There is a slight increase in the vertical range of intertidal habitats in the East Basin from 2015 to 2065. The tidal inlet design is sufficient in cross-sectional area and bed elevation to convey full tidal circulation in all wetland basins. The full range of salt marsh habitats should occur on-site once they become established. Tidal muting from shoaling could constrain the tidal range and distribution of habitats, indicating maintenance dredging could be important in preserving habitat areas. Sea level rise may offset the effects of shoaling in tidal muting. Alternative 2A shows tidal muting 0.1 feet in the East Basin in 2015. No muting occurs at any location for Alternatives 2A and 2B in 2065.

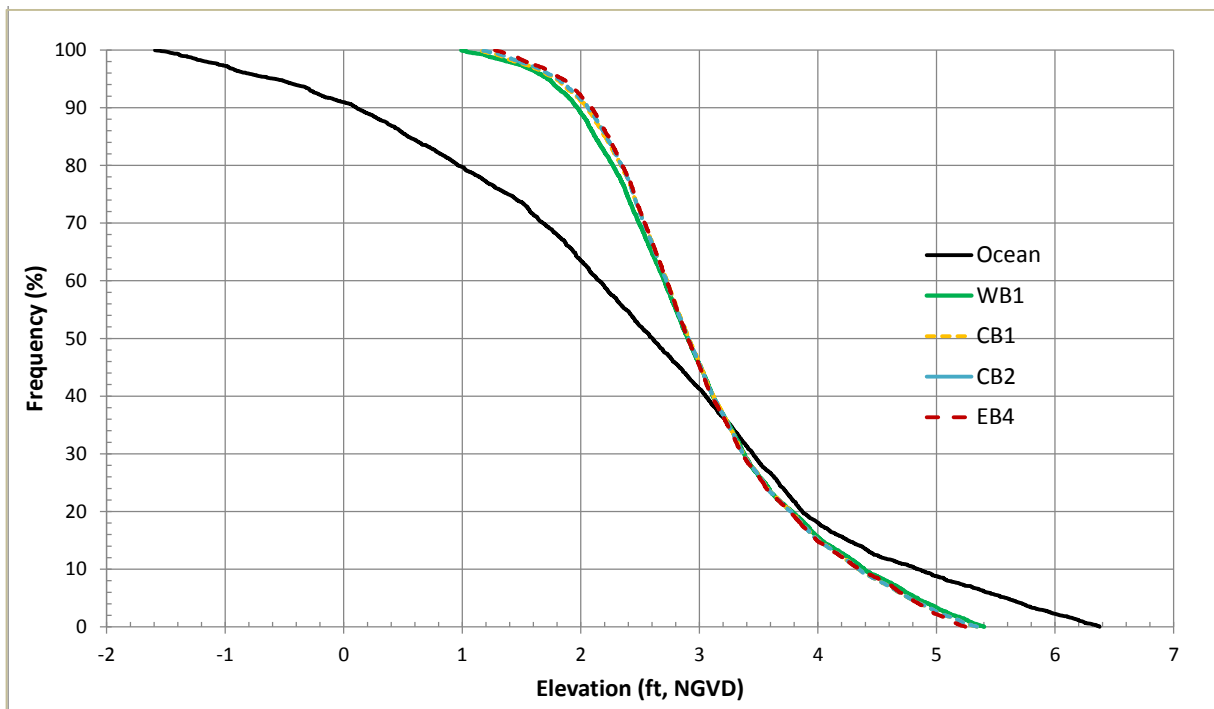


Figure 4-37: Inundation Frequency for No Project at 2065

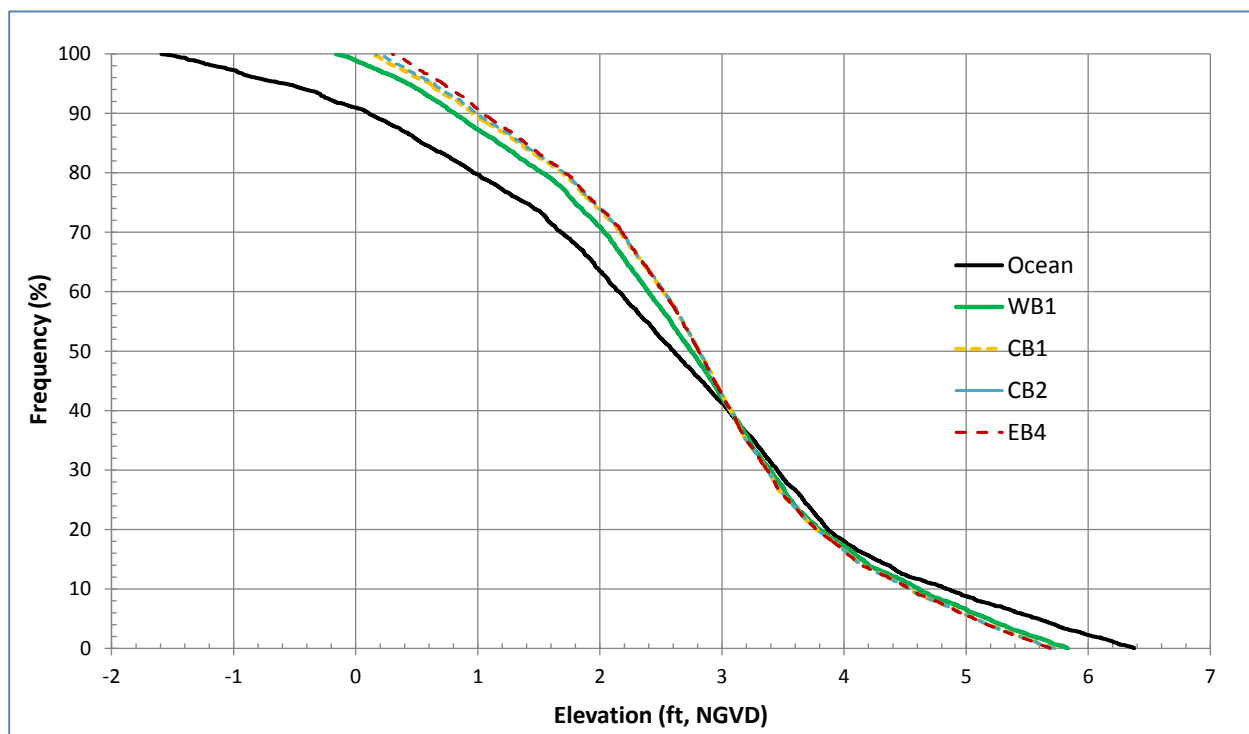


Figure 4-38: Inundation Frequency for Alternative 1A at 2065

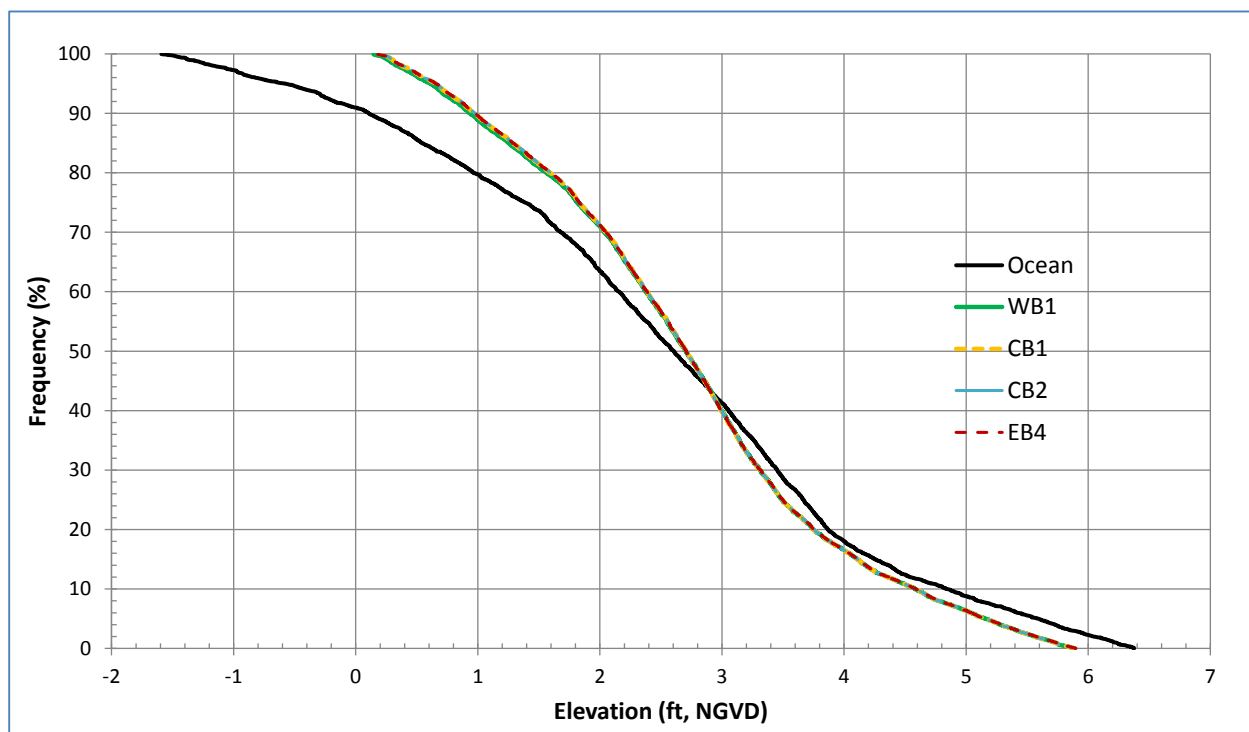


Figure 4-39: Inundation Frequency for Alternative 1B at 2065

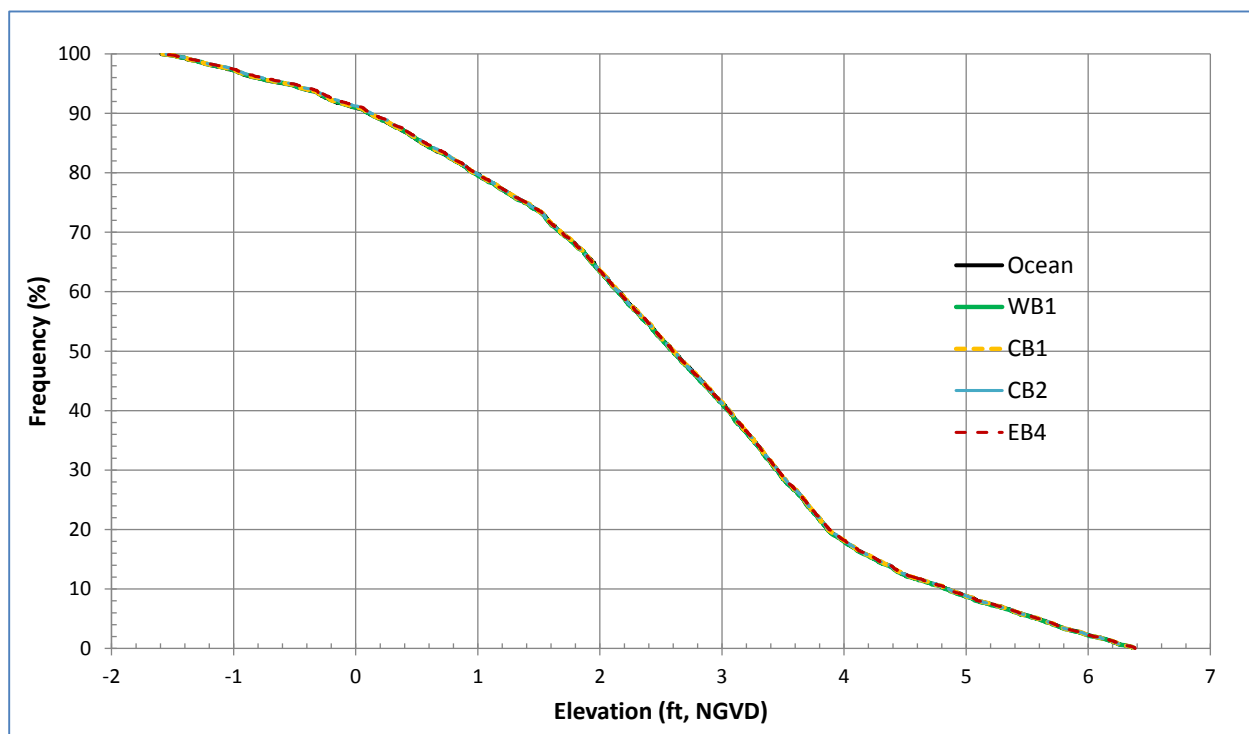


Figure 4-40: Inundation Frequency for Alternative 2A at 2065

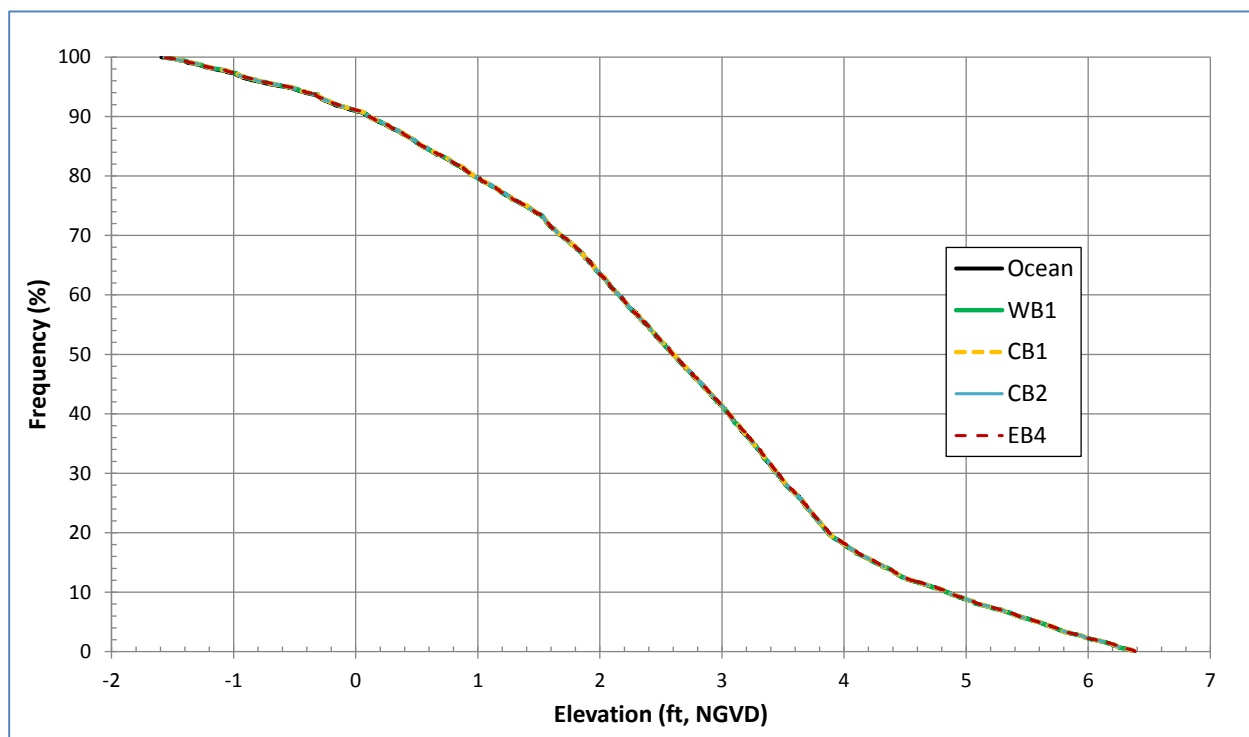


Figure 4-41: Inundation Frequency for Alternative 2B at 2065

4.4.3.3 Tidal Hydraulics at the Tidal Inlet

Tidal hydraulics at the tidal inlet for 2065 are analyzed in comparison to the analysis presented for immediate post-construction conditions in 2015, assuming no shoaling. The depth averaged tidal flow velocities at the center of the inlet for No Project and all alternatives are listed in Table 4-11 for both 2015 and 2065. Columns (5) and (6) show the percentage of time of tidal ebbing and flooding at the inlet. The duration in percentage of time that ebb and flood flow velocities are higher than 3 fps is shown in Columns (8) and (9) (a velocity of 3 fps is high enough to suspend the sand and to scour the inlet). The other factors influencing inlet stability are sediment delivery by currents and waves, so this scour parameter is not the only factor to consider and will be further addressed in the subsequent inlet stability study. Columns (8) and (9) serve to compare the duration of high flow velocity conditions between tidal floods and ebbs. The values are the percentage of time the velocity is higher than 3 fps over the total duration of ebbing/flooding.

Table 4-11: Summary of Tidal Inlet Hydraulic Results at 2065

Alternative (1)	Year (2)	Maximum Velocity at Inlet (fps)		Overall Duration at Inlet (%)		Ratio of Overall Duration of Ebb versus Flood at Inlet (%) (7)	Duration of Velocity over 3 fps at Inlet (%)	
		Ebb (3)	Flood (4)	Ebbing (5)	Flooding (6)		Ebbing (8)	Flooding (9)
Existing	2015	5.1	3.2	60	40	1.48	14.0	1.0
	2065	6.4	4.3	55	45	1.23	31.0	9.0
1A	2015	5.2	1.8	52	48	1.10	9.5	0.0
	2065	6.4	2.2	50	50	1.00	12.0	0.0
1B	2015	6.9	2.1	52	48	1.09	15.3	0.0
	2065	7.2	2.5	51	49	1.05	14.0	0.0
2A	2015	3.0	2.6	51	49	1.03	0.1	0.0
	2065	3.5	2.9	51	49	1.03	2.0	0.0
2B	2015	7.2	6.7	50	50	1.00	16.0	18.0
	2065	5.8	5.3	51	49	1.03	12.0	10.0

Tidal inlet flow velocity changes and potential impacts of sea level rise on tidal inlet flow velocity, assuming no shoaling, are summarized below.

- For No Project, with a relatively narrow and shallow existing inlet, the inlet tidal flow velocity increases as a result of the increased tidal prism from sea level rise. However, the tidal inlet depth is still a limiting factor due to the constraint imposed by the shallow bedrock and cobble sill in the nearshore. The inlet velocity increases about 25 percent in 2065 from 2015, which may lead to a more stable inlet than the current condition.
- For Alternative 1A, similar to No Project condition, the tidal inlet velocity also increases about 23% from 2015 to 2065.

- For Alternative 1B, the inlet velocity increases slightly in 2065 compared to 2015. However, the durations of inlet velocities exceeding 3 fps are reduced as a result of a deeper inlet from the effects of sea level rise. This may lead to increased inlet shoaling, which could then cause velocities to rise again as the cross-section is constricted leading to a new form of equilibrium.
- For Alternative 2A, both tidal ebbing and flooding flow velocities increase, and the duration of high velocity conditions (higher than 3 fps) is slightly lengthened as a result of reduced muting. Therefore, the tidal inlet will be relatively more stable under the sea level rise condition.
- For Alternative 2B, both tidal ebbing and flooding flow velocities are reduced, and durations of high velocity conditions (higher than 3 fps) are shortened. These effects are due to the increased depth of the tidal inlet from sea level rise, while the tidal prism remains constant. The inlet depth may increase to a point at which tidal flow velocities slow and shoaling occurs. Shoaling in the inlet could fill a portion the channel cross-section and cause tidal flow velocities to increase once again and lead to a new form of equilibrium.

5.0 SUMMARY AND CONCLUSIONS

Numerical modeling of the hydraulic characteristics of the San Elijo Lagoon under various storm and tide conditions was performed for conditions immediately following restoration (2015) and anticipated conditions in 50 years (2065). The RMA model previously used for this type of study by the USACE was updated to increase the range of analysis and reflect the present design alternatives.

The purpose of the modeling was to:

- Analyze the potential for increased flooding of adjacent areas from restoration;
- Predict the hydrology (inundation frequency) required to establish new wetland habitat areas;
- Confirm the sizes of the openings of a new tidal inlet, and channels under highway and railroad bridges;
- Provide flow velocity estimations to assist in evaluating the potential long-term sustainability of the tidal inlet (in a subsequent study); and
- Provide the hydraulics for water quality modeling (in a subsequent study).

Modeling was performed for existing conditions (No Project) and four alternatives consisting of:

- Alternative 1A – Minimum Changes;
- Alternative 1B – Maximum Habitat Diversity, Existing Inlet Location;
- Alternative 2A – Maximum Habitat Diversity, New Inlet Location; and
- Alternative 2B – Maximum Tidal Expression.

Modeling included the following scenarios:

- 100-Year return period stormflows coupled with highest measured high tides to determine maximum future water levels; and
- Tidal conditions in 2015 (immediate post-construction) and in 2065 (50 years after construction) to determine Lagoon hydraulics and hydrology. Conditions in 2065 are characterized by a two foot rise in sea level from conditions in 2015. Assumptions regarding shoaling, sedimentation and other causes of tidal muting were not considered in this portion of the analysis. These conditions will be addressed in subsequent studies.

Results consist of the following:

1. Storm flows combined with highest measured high tides will result in elevated water levels throughout the Lagoon. Specifically, in 2015:
 - a. No Project conditions result in Manchester Avenue being flooded by several feet along the East Basin.
 - b. Alternative 1A (with the inlet in the existing location) provides limited flood reduction potential, however Manchester Avenue will still flood along the East Basin although flood water levels will be lowered.
 - c. Alternatives 1B, 2A and 2B reduce flood elevations to below Manchester Avenue all along its length due to expanded channel cross-sections under all bridges.
2. In 2065, Manchester Avenue will experience storm flow flooding along both the Central and East Basins for all alternatives due to adverse effects of sea level rise.
3. Tidal flows vary between alternatives as reflected by the following results for 2015:
 - a. For No Project, tidal flows are restricted due to the narrow and meandering channel between Highway 101 and the Railroad, and the presence of a sill at the bed. Tidal ranges are significantly muted for both high and low tides, and muting increases progressively from the West Basin through the East Basin.
 - b. For Alternatives 1A and 1B (with the inlet in the existing location) tidal muting is significantly reduced and circulation is improved in the wetland basins compared to existing conditions. This is due to expansion of the cross-sections under all bridges. A certain amount of muting still will exist, and is greater in the Central and East Basins than in the West Basin.
 - c. For Alternatives 2A and 2B (with the new inlet location) tidal muting is further reduced and circulation is most improved in the wetland basins compared to alternatives using the existing inlet location. This is due to further expansion of the cross-sections under all bridges. Minimal to no muting will exist before sand shoals form within the Lagoon.
4. Tidal inundation frequency resulting from tidal hydrology significantly influences the habitat type and distribution on-site. Results for 2015 include:
 - a. For No Project, the vertical zonation of intertidal habitat is relatively narrow at approximately 3 to 4 feet. A progressive decrease in the vertical range of intertidal habitat occurs with distance to the east. A range of salt marsh habitats can occur on-site, but their areas will be constrained by the tidal range, and the habitat distribution on-site may be dominated by fewer species more suited to the muted tidal elevations.
 - b. For Alternatives 1A and 1B, the vertical zonation of intertidal habitat increases, ranging from 5.7 feet in the West Basin to 5.2 feet in the Central and East Basins. A

- greater range of salt marsh habitat can occur on-site, but their areas will still be constrained by the tidal range. Creating a greater range of elevations on-site for Alternative 1B with grading/dredging would be appropriate to provide greater habitat diversity. Tidal muting from shoaling (addressed in a subsequent study) would constrain the tidal range and distribution of habitats, indicating maintenance dredging would be important in preserving habitat areas.
- c. For Alternatives 2A and 2B, the vertical zonation of intertidal habitats is 8.0 feet in the West Basin and 7.9 feet in the East Basin. The tidal inlet design is large enough to convey full tidal circulation in all wetland basins. The full range of salt marsh habitats should occur on-site once they become established. Grading and disturbance to create appropriate grades for habitat would be appropriate to provide greater habitat diversity. As with previous alternatives, muting would constrain the tidal range and distribution of habitats, indicating maintenance dredging would be important in preserving habitat areas.
5. Data of tidal inlet hydraulics are useful to help determine tidal inlet stability, to be fully addressed in a subsequent study. For 2015, the maximum ebb tidal velocity is greater than the flood tidal velocity for all scenarios (the existing condition, and all alternatives) suggesting possible expulsion of sediment, rather than sedimentation. However, the existing inlet is not stable, so the data need scrutiny in an inlet stability study. Also, the peak ebb tidal velocity at the inlet is higher than the peak flood tidal velocity for each scenario, indicating that the inlet is ebb-dominant and net sediment flow could be out of the Lagoon rather than into the Lagoon for all scenarios. Greater stability is expected for the new inlet location alternatives (2A and 2B) due to increased cross-sectional area and depth, and available area to manage sediment in the Lagoon.
 6. For 2065, tidal flow modeling results assuming no shoaling show that tidal muting in wetland basins consistently decrease as sea level rises. However, the reduction in tidal muting varies from alternative to alternative, and from location to location. Tidal muting will still occur for No Project, and for Alternatives 1A and 1B. No tidal muting will occur for Alternatives 2A and 2B.
 7. Tidal inundation frequency results for 2065 include:
 - a. For No Project, the vertical zonation of the intertidal habitat band increases in all basins. However, the vertical zonation (range of occurrence) of intertidal habitat is still relatively narrow compared to an un-muted, open-ocean condition.
 - b. For Alternative 1A, the intertidal habitat band increases in all basins, but any tidal muting from shoaling would further constrain the elevations and distribution of salt marsh habitat, but may be offset to some extent by sea level rise, and this applies to all site modification alternatives.
 - c. For Alternative 1B, the intertidal habitat band increases vertically, and proposed channel widening under the I-5 Bridge will eliminate tidal muting between the Central Basin and the East Basin.

- d. For Alternatives 2A and 2B, inundation frequencies in the wetlands closely mimic that in the ocean in 2065, and the vertical zonation of intertidal habitats is maximized in all basins. The tidal inlet is sufficient in cross-sectional area and bed elevation to convey full tidal circulation in all wetland basins.
8. Tidal inlet hydraulics for 2065 assuming no shoaling consist of:
- a. For No Project and Alternative 1A, the inlet velocity may increase in 2065 from 2015, which may lead to more sand scour than the current condition; however, the duration is shorter;
 - b. For Alternative 1B, the inlet velocity is slightly increased in 2065. The durations of inlet scour velocities may be lengthened as a result of increased tidal prism (from sea level rise) if no shoaling occurs. The inlet may be more stable with sea level rise. This is to be determined in a subsequent study for all alternatives.
 - c. For Alternative 2A, both tidal ebbing and flooding flow velocities increased, and the duration of high velocity conditions (higher than 3 fps) is slightly lengthened as a result of reduced muting. Therefore, the tidal inlet will be relatively more stable under the sea level rise condition.
 - d. For Alternative 2B, both tidal ebbing and flooding flow velocities are reduced, and durations of high velocity conditions (higher than 3 fps) are shortened. These effects are due to the increased depth of the tidal inlet from sea level rise, while the tidal prism remains constant. The inlet depth may increase to a point at which tidal flow velocities slow and shoaling occurs. Shoaling in the inlet could fill a portion the channel cross-section and cause tidal flow velocities to increase once again and lead to a new form of equilibrium.

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